SMART GROWTH INDEX®

A Sketch Tool for Community Planning

Reference Guide

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Prepared for the

U.S. ENVIRONMENTAL PROTECTION AGENCY

by

Criterion Planners/Engineers

with

Fehr & Peers Associates

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1. INTRODUCTION

Overview

Smart Growth INDEX (SGI) is a sketch tool for simulating alternative land-use and transportation planning scenarios and evaluating their outcomes using indicators of environmental performance. It is intended as a planning support tool that can be applied in any community that has a geographic information system (GIS).

SGI performs sketch-level analysis in two basic modes of operation: 1) spatial "forecasts" of community growth over time; and 2) "snapshots" of community conditions at a single point in time. The forecast mode allows an exogenous growth forecast to be spatially allocated for up to 20 years according to user-defined land-use controls, transportation system capabilities, and environmental protection and economic development policies. The snapshot mode allows the same land-use, transportation, and environmental parameters to be specified for a given point in time. Both forecast and snapshot outcomes are measured by indicators such land consumed, travel generated, and pollution emitted.

Applications

SGI is intended to be a sketch tool for collaborative planning among community stakeholders engaged in the following kinds of applications:

Forecast Sketches

- Regional growth management plans.
- Comprehensive land-use plans.
- Large area master plans.
- Transportation plans.
- Environmental impact statements.

Snapshot Sketches

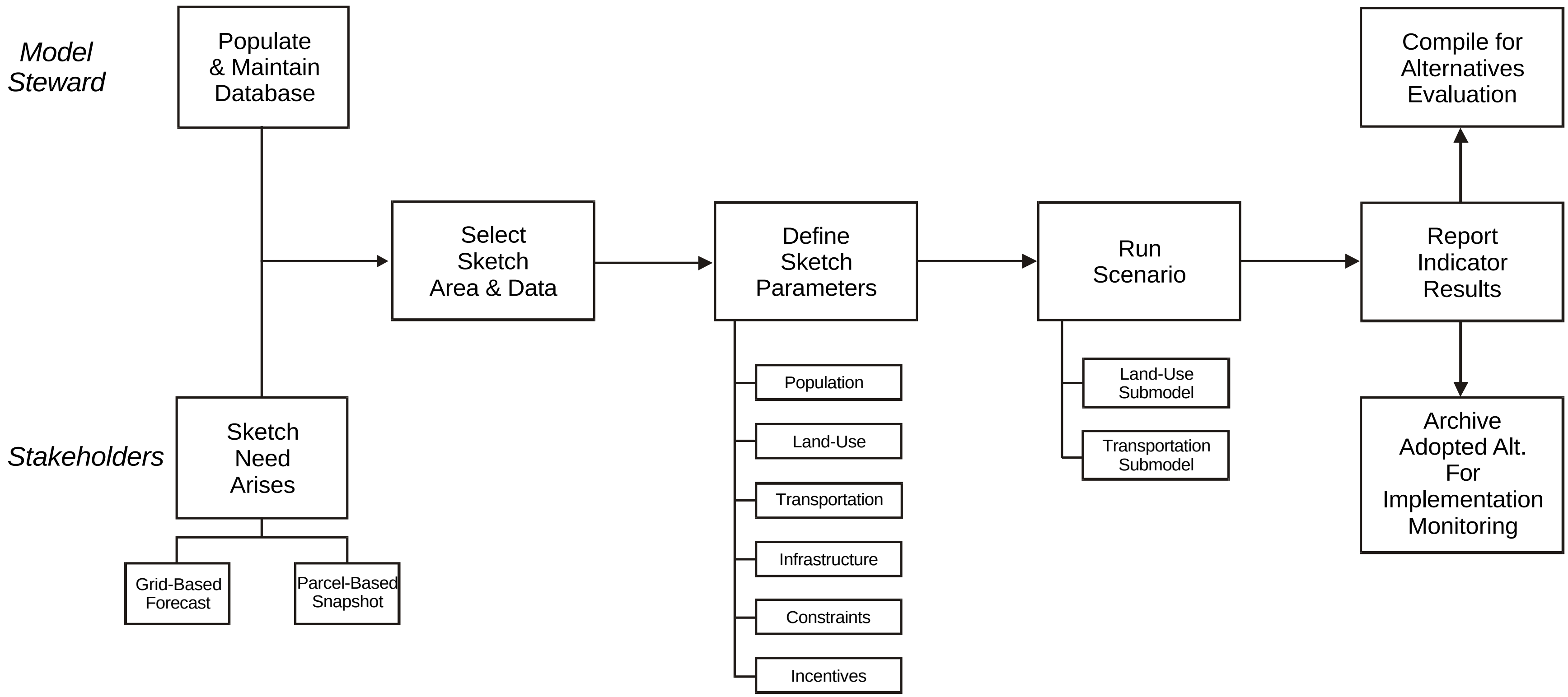
- Neighborhood plans.
- Land development proposal evaluations.
- Transportation corridor studies.
- Environmental reviews.
- Special projects, e.g. brownfield vs. greenfield development comparisons; transit station area plans.

Figure 1 presents a generalized view of the modeling process for such applications. Additional guidance on community planning applications and the use of indicators is provided in Appendix D.

What SGI Isn't

As a sketch tool, SGI has limitations that need to be clearly understood by users. It is not a highly technical model, such as URBANSIM or TRANUS that attempt to simulate integrated land-use/transportation dynamics with considerable precision. SGI does not attempt to predict future conditions exactly, but instead estimates what would happen if clearly defined policy choices are made and assumptions concerning the future prove to be correct. SGI uses a very simplified "gravity" method of modeling growth that does not take into account such factors as land prices, household income and relocation, and freight movement. It is not a calibrated transportation planning model suitable for evaluating major investments or demonstrating regulatory compliance; nor is it a traffic engineering or highway design model. SGI does borrow or adapt certain elements and methods from these and other place-making tools, but its limitations need to be recognized.

Figure 1
GENERALIZED SMART GROWTH INDEX MODELING PROCESS



Community Requirements

SGI is a Windows application using Visual Basic and ESRI's MapObjects for geographic functions. In order to use it, a community must have the following:

- A 300 MHz or higher PC with at least 128 MB of RAM (256 MB is preferred); and a Windows operating system.

- A GIS with the database inputs described in Section 2. If it is not a GIS that operates with shapefiles in the format developed by Environmental Systems Research Institute (ESRI), the community must have a means of converting its GIS coverages to ESRI shapefile format. Quality control needs to be exercised with any non-ESRI file conversions to insure that proper shapefiles are created.

- One or more model stewards with advanced experience in GIS and transportation modeling that can be responsible for SGI installation and maintenance. Once the model is installed and its database is populated, it is generally usable by persons who need only basic GIS familiarity.

Documentation

In addition to this Reference Guide, SGI is documented in a Getting Started Guide available under separate cover and with an on-line help system embedded in the software. Persons desiring technical user information should consult the Getting Started Guide and on-line help system.

2. INPUTS

SGI inputs differ depending on whether it is being used for forecast or snapshot sketching. In both cases, there are certain minimum requirements for model operation and several optional items to enhance the sketch analysis. For both forecast and snapshot sketches, inputs are either imported as GIS coverages in "shapefile" format or entered as user-defined parameters.

Minimum Inputs

<u>GIS Coverages</u>

1) Existing housing by type (single-family or multiple-family) and dwelling unit count in point shapefile format for forecast sketches. Point data represents objects that have discrete locations that are too small to be depicted as areas. In this case, a single point represents the location of a single residential structure containing one or more dwelling units. Sources for this data include property tax databases, 911 emergency systems, and private data vendors. In cases where housing characteristics have been attributed to parcel polygons, it is sufficient to attach those attributes to a centroid of the parcel in order to create the required point coverage. It is not necessary to have the points located precisely where structures are located on parcels.

2) Existing employment by type (retail, service or all other) and job count in point shapefile format. In this case, a single point represents the location of a single business establishment containing one or more employees. Sources for this data include regional transportation models, business license databases, 911 emergency systems, and private data vendors. Some states distribute employer payroll tax information known as "ES 202" data that contains the required items. As with housing, it is not necessary for employment points to be located precisely where business structures are situated on parcels.

3) Land-use plan designations by class. This coverage must consist of "areawide" polygons attributed with planned land-use designations. Parcel coverages attributed with planned land-use are not advisable; rights-of-way should also be excluded. The model will accept any local system of land-use plan classification as long as one system is used for the entire sketch area. In cases where multiple jurisdictions in a single region have multiple classification systems, they must be consolidated into a single system before being imported into SGI. Users may enter existing adopted plans, or entirely new alternatives being considered as part of a plan update process. Sources for this data include local and regional agencies with land-use planning responsibilities.

4) Existing land-use with housing by type (single-family or multiple-family) and dwelling unit count in a polygon shapefile format for snapshot sketches. The shapefile should be a parcel coverage. Sources for this data include local government agencies and property tax databases.

5) Street centerlines attributed by functional class, numbers of traffic lanes on each segment if available, and sidewalk presence (for snapshots). If number of lanes is not available in GIS coverage, the user may enter an average number in the following section on user-defined parameters. Also, GIS coverages of future streets must be provided for designated years of a forecast period to simulate the addition of new streets over time. Sources for this data include metropolitan planning organizations, regional planning agencies, and local government agencies with transportation responsibilities.

6) Transit routes by type (bus, rail) for forecast sketches; transit stops by type for snapshot sketches. Sources for this data include transit agencies, metropolitan planning organizations, and regional planning agencies with transportation responsibilities.

User-Defined Parameters

1) Growth projection. For forecast sketches, an exogenous estimate of population and employment growth for each interval year to a horizon year (up to a maximum of 20 years). The population forecast must assign new residents to either single-family or multi-family housing types. The employment forecast must categorize jobs in three categories of retail, service and all other. Sources for this data include state agencies responsible for statewide projections that are disaggregated for communities, and metropolitan planning organizations or regional planning agencies that prepare local projections.

2) Urban size category. For forecast sketches, this is the population category of the urban area in which the sketch area is located. The user selects an appropriate category from a population range list derived from U.S. census data. The only data required is a local urban population value.

3) Commuteshed population. For forecast sketches, this is the user's best estimate of baseline and horizon year populations within a 40-mile radius of the sketch area boundary. For snapshot sketches, actual values for total population and employment for the commuteshed or entire region (whichever is larger) for the base sketch. Data sources for this estimate include metropolitan planning organizations and regional planning agencies.

4) Transit rail availability. For forecast sketches, this is a “yes/no” indication of rail transit presence in the region.

5) Levels of service. For forecast sketches, average existing peak-hour levels of service (LOS) on all freeways and arterials for the combined sketch area and commuteshed. These are entered with an LOS scale that rates congestion levels from minor (A) to severe (F). Alternatively, regionwide and sketch area VMT and free-flow and congested traffic network link speeds can be used from a local transportation model. Sources of data include state transportation agencies, metropolitan planning organizations, and local government agencies with transportation responsibilities.

6) Vehicle trips and miles traveled. For snapshot sketches, baseline total daily VT and VMT per capita for the sketch area or a comparable developed area (see Appendix A for details). Data sources include transportation models operated by regional and local agencies.

7) Average number of lanes by functional class and year of service for forecast sketch areas, if actual lane count is not contained in the street centerline GIS coverage. Data sources include transportation models operated by regional and local agencies.

8) Allowable densities for each land-use class (maximum) in dwellings per acre for residential uses, and floor area ratios for non-residential uses. This information is taken from land-use plans administered by regional and local agencies.

9) Ratios of non-residential floor area to number of employees for non-residential land-use classes. This information should be derived from local or regional real estate and employment databases managed by planning agencies.

10) Ratios of residential to non-residential uses for mixed-use land-use classes (if a jurisdiction has such classes). This information should be derived from local real estate trends.

11) Percent of maximum allowable dwelling units to be infilled in existing residential areas. This can either be derived from regional or local policies, or set at various levels to test the effects of alternative infill policies.

12) Transportation fuel consumption rates. Users may select national default values or enter local rates derived from state energy and transportation databases.

13) Climate region and building energy demand coefficients. Users may select regional defaults or enter values derived from state energy databases.

14) Transportation and building air pollutant and greenhouse gas emission coefficients. Users may select national default values or enter values derived from state air quality databases.

15) Residential water consumption rates. Users may select regional default values or enter rates derived from local water agency databases.

Optional GIS Coverages

1) Features that may be used to constrain urbanization because of their nondevelopable status, e.g. agricultural soils, steep slopes, floodplains, wildlife habitat areas, urban growth boundary. Sources for these coverages include regional and local agencies with land-use planning responsibilities.

2) Incentive areas that are preferred for development due to policy incentives, e.g. transit corridors, brownfields, enterprise zones. Sources for these coverages include regional and local agencies with land-use planning responsibilities.

3) Existing and planned infrastructure (e.g., water and sewer) service areas. Coverages of "planned" service areas must include the year of intended servicing. Sources for these coverages include regional and local agencies with capital improvement planning responsibilities.

4) Existing daily traffic counts by street segments. Data sources include metropolitan planning organizations and local agencies with transportation responsibilities.

5) Local jurisdiction boundaries (if results are to be reported by jurisdiction). Data sources include regional planning agencies and local governments.

6) Other subarea boundaries such as traffic analysis zones or census tracts that may be used as convenient ways to create sketch area boundaries and/or report results. Data sources include metropolitan planning organizations, regional planning agencies, and local governments.

3. OUTPUTS

SGI outputs differ depending on the type of sketch being prepared. For forecast sketches, a set of indicators are scored and mapped for interval and horizon years. For snapshot sketches, a similar set of indicators are scored and mapped for a single point in time. Outputs for both sketch types also include tabular and mapped allocations of land-use, housing, and employment. Users can also document the parameter settings they use for a particular sketch.

Indicators are listed below by sketch type. Definitions, illustrative scores, and guidelines for applying indicators are provided in Appendix D.

Forecast Indicators

1) Growth compactness (persons/sq.mi. in developable portion of sketch area, including residents and employees).

2) Population density (persons/sq.mi. in total sketch area, including residents and employees).

3) Incentive area use for housing (% of total housing capacity utilized in user-designated incentive areas).

4) Incentive area use for employment (% of total employment capacity utilized in user-designated incentive areas).

5) Jobs/workers balance (ratio of total jobs to total employed residents assuming a constant 1.4 workers per household).

6) Housing density (DU/gross acre).

7) Housing transit proximity (% of all DU within 1/4 mi. of transit route).

8) Residential energy use (MMBtu/yr/capita for housing and auto travel).

9) Residential water use (gal/day/capita).

10) Employment density (employees/gross acre).

11) Employment transit proximity (% of all employees within 1/4 mi. of transit route).

12) Vehicle trips (total VT/day/capita).

13) Vehicle miles traveled (total VMT/day/capita).

14) Vehicle hours traveled (total VHT/day/capita).

15) Vehicle hours of delay (total VHD/day/capita).

16) Auto driver vehicle mode share (percent of total daily person trips by auto driver.)

17) Auto passenger mode share (percent of total daily person trips by auto passengers).

18) Transit mode share (percent of total daily person trips by transit).

19) Walk/bike mode share (percent of total daily person trips by walk/bike).

20) Auto travel cost ($/yr/capita).

21) Oxides of nitrogen (NO_X) vehicle emissions (lbs/yr/capita).

22) Oxides of sulphur (SO_X) vehicle emissions (lbs/yr/capita).

23) Hydrocarbon (HC) vehicle emissions (lbs/yr/capita).

24) Carbon monoxide (CO) vehicle emissions (lbs/yr/capita).

25) Particulate matter (PM) vehicle emissions (lbs/yr/capita).

26) Carbon dioxide (CO_2) vehicle emissions (tons/yr/capita).

Snapshot Indicators

1) Population density (persons/sq.mi. including residents and employees).

2) Use mix (index of use dissimilarity among one-acre grid cells).

3) Jobs/workers balance (ratio of total jobs to total employed residents).

4) Land-use diversity (index of sketch area population/employment mix in relation to regional mix).

5) Residential density (dwellings per net acre of residential land).

6) Single-family housing share (single-family % of total dwellings).

7) Multi-family housing share (multi-family % of total dwellings).

8) Housing proximity to transit (% of dwellings within 1/4 mi. of transit stops).

9) Housing proximity to recreation (% of dwellings within 1/4 mi. of park).

10) Residential energy consumption (MMBtu/yr/capita for housing and auto travel).

11) Residential water consumption (gal/day/capita).

12) Employment density (employees per net acre of employment land).

13) Employment proximity to transit (% of employees within 1/4 mi. of transit stops).

14) Sidewalk completeness (% street frontage with sidewalks).

15) Pedestrian route directness (average ratio of walking distance from origin points to central node versus straight line distance between same points; origin points are 5% random sample of all parcels).

16) Street network density (street centerline mi./sq.mi.)

17) Street connectivity (ratio of intersections vs. intersections and cul-de-sacs).

18) Pedestrian environment design (composite index of street network density, sidewalk completeness, and pedestrian route directness).

19) Vehicle trips (total VT/day/capita).

20) Vehicle miles traveled (total VMT/day/capita).

21) Auto travel cost ($/yr/capita).

22) Open space (% of total sketch area in user-defined open space land-use classes).

23) Park space availability (park acres/1,000 persons).

24) Carbon monoxide (CO) vehicle emissions (lbs/yr/capita).

25) Hydrocarbon (HC) vehicle emissions (lbs/yr/capita).

26) Sulphur oxide (SO_X) vehicle emissions (lbs/yr/capita).

27) Particulate matter (PM) vehicle emissions (lbs/yr/capita).

28) Carbon dioxide (CO_2) vehicle emissions (tons/yr/capita).

Other Standard Reports for Both Forecast and Snapshot Sketches

1) Land allocations by land-use type.

2) Housing by type (single, multiple).

3) Jobs by type (retail, service, other).

4) User-selected parameter settings.

4. FORECAST SKETCHES

This section describes the general modeling sequence that users will follow to prepare forecast sketches, and the principal functions of the model in the process. The basic operation allows a given population projection to "grow" in different geographic ways by varying an area's:

- Land-use plan
- Environmental constraint areas
- Development incentive areas
- Transportation system capabilities
- Infrastructure service areas

Outcomes for these sketches are most appropriately judged in terms of relative differences between indicator scores, rather than in absolute score values.

<u>Modeling Sequence</u>

1. *Sketch management.* The user initiates a forecast sketch by either: 1) opening an existing sketch; 2) creating an entirely new sketch; or 3) copying an existing sketch to create a new sketch with modifications that do not justify an entirely new sketch. Existing sketches may also be deleted at this point.

2. *Select sketch boundary.* The user selects all or any portion of the total area covered by the SGI database by either: 1) using a full layer from the database; 2) using a previous sketch boundary; or 3) selecting a set of features, e.g. a group of census tracts or TAZs.

3. *Set grid cell size.* The user selects a range of grid cell sizes, from a minimum of ten acres to a maximum of 200 acres. Once the cell size is selected, the model places the grid over the land-use coverage and the acreage of each land-use class within each cell is measured.

4. *Specify user-defined parameters.* The user is asked to set various parameters concerning land-use, transportation, and other resource conditions affecting a given scenario, including:

   - Allowable densities and occupancies for land-use classes.
   - Household travel demand profile (vehicle ownership, trip generation, mode choice).
   - Mode performance factors for auto, high occupancy vehicle, and transit.
   - Average levels of service for arterials/freeways.
   - Household water and energy use, and energy pollutant emissions.

5. *Define baseline growth scenario.* The user enters an exogenous population and employment growth estimate for each interval year up to a horizon year (maximum of 20 years). The population forecast must assign new residents to either single-family or multi-family housing types, and the average number of persons per household must be specified by housing type. The employment forecast must categorize jobs in three categories of retail, service, and all other.

6. *Specify development constraints.* If available, the user may select constraining features from the model's database. These might include agricultural lands, steep slopes, floodplains, wetlands, wildlife habitat, or an urban growth boundary. In effect, the user is free to define what constitutes a development constraint under local circumstances and to populate the database accordingly.

7. *Specify development incentives.* If available, the user may select incentive features from the model's database to create special attractiveness for growth in selected areas. Examples include transit corridors, brownfields, and enterprise zones. Again, the user is free to define what local features constitute incentives.

8. *Apply constraints and incentives to begin growth attractiveness determination.* The model calculates the portion of cells that have been constraint-designated and made unavailable for growth, and subtracts that from each cell's gross area to solve for net area available for growth. The user is also given a list of the incentive types and an opportunity to set levels of increased growth attractiveness for each type of applied incentive coverage. The user expresses this increased attractiveness as any amount greater than 100% of a cell's base attraction score up to a maximum of 200% (a cell's base attraction score is its travel accessibility score as calculated below).

9. *Calculate growth attractiveness in terms of travel accessibility.* Travel accessibility for a developable cell is determined by its proximity (inverse of travel time) to related land-uses. For residential, retail, and other employment cells, these ratings are determined as follows:

   - For each developable residential cell, the accessibility rating is each cell's relative proximity to all employment cells (work-trip attractors), compared with the work-trip proximity for all other developable residential cells.

   - For each developable retail cell, the accessibility rating is the cell's relative proximity to all shopping-trip generators (home-based-other trip accessibility to all residential cells, and non-home-based trip proximity to all non-residential cells), compared with the shopping-trip proximity for all other developable retail cells.

- For other developable employment cells (service and all other jobs), the accessibility rating is the cell's relative proximity to all other non-residential cells (non-home-based trip proximity), compared with the non-home-based trip proximity for all other developable employment cells.

In each case, proximity is calculated through the transportation submodel described in Appendix A. In general, the submodel steps involve:

a) Measuring the airline distance from the origin cell to all destination cells containing compatible uses (as defined above).

b) Converting the airline distances to distances traveled over the street network to determine the relationship between airline distance and travel distance on local streets, arterials, and freeways. This is accomplished by the model's random selection of five destination points for each cell, and a street network distance measurement for those origin/destination pairs.

c) Computing cell-to-cell travel times by applying average congested arterial and freeway speeds.

d) Converting the cell-to-cell travel times to cell-to-cell impedance using a friction-factor formula.

e) Determining the number of trip attractions in the destination cell for the relevant trip purpose specified above (home-based-work, home-based-other, and/or non-home-based).

f) Multiplying the number of attractions in the destination cell by the cell-to-cell travel impedance between the origin and destination cells to determine cell-to-cell accessibility.

g) Repeating for all other compatible destination cells, and sum origin cell's accessibility to all compatible destination cells to obtain composite accessibility.

h) Computing composite accessibility for all origin cells, and sum to obtain area-wide accessibility total.

i) Calculating each origin cell's share of total area-wide accessibility by dividing its individual composite accessibility by the area-wide accessibility total.

The above calculations yield up to three accessibility scores for each cell: 1) a residential accessibility score based on prospective residents' proximity to jobs, 2) a retail accessibility score based on proximity to prospective shoppers' homes and work places, and 3) an employment accessibility score based on proximity to other employment and services. These scores are used independently when allocating growth in housing, retail jobs, and non-retail jobs, respectively.

10. *Rate growth attractiveness in terms of infrastructure efficiency.* In this step, the model refers to the GIS coverages of existing and planned infrastructure service areas. Developable cells are scored in terms of their presence in such areas (serviced, 1.25; planned for service, 1.1; no service planned, 0.75). The user is able to alter this scoring scale in order to weight the importance of infrastructure in relation to the travel accessibility score. The year of planned service area expansions must be provided in the database in order for the model to correctly adjust scores during the interval years of a growth scenario.

11. *Calculate overall attractiveness for growth.* The model multiplies each developable cell's travel accessibility score by its infrastructure score, and any applicable incentive scores, to obtain an overall growth attractiveness score.

12. *Control total check.* The model checks the user-supplied growth projection against the land deemed developable to insure that enough land area is available to accommodate projected residential and employment growth. In the event the model finds insufficient land available, the user is given the option of changing land-use densities and/or constraint designations.

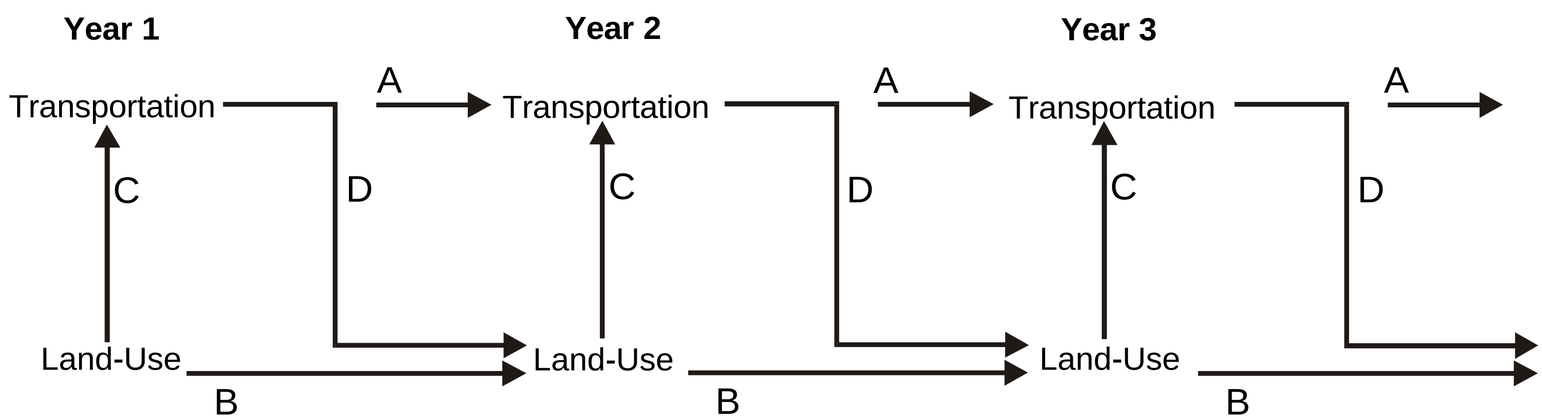
13. *Allocate housing and employment growth spatially.* The model performs iterations of incremental growth allocation to developable cells for each interval year out to the horizon year. At the beginning of each iteration, all developable cells are grouped into 10 deciles according to their final growth attractiveness score. Fifty percent of each interval year's new dwelling units and employment are allocated to cells in the most attractive decile, half of that (25%) in the second most attractive decile, half again (12.5%) in the third most attractive decile, and so on to the least attractive decile which gets 0.2% of the new dwelling units and employment. This approach insures that, while most of the growth is allocated to the most attractive cells, some lower ranking cells will also grow to reflect development that is not always optimal or rational. If a decile cannot physically absorb the allocations described above, any excess is passed to the next lower decile. Additionally, the user is given the option of changing the decile allocation quantities if desired. Within each decile, cells are randomly selected for growth subject to applicable land-use designations, e.g. housing will only be assignable to residentially-designated cells. Random selection of cells is intended to reflect spatial growth that does not necessarily occur first, or at all, at the most attractive sites, due to either different

perceptions of attractiveness or the relative similarity of attractiveness across a range of sites. The number of cells selected for growth in each decile is the number necessary to allocate all of the decile's share of the total growth at a rate of 20 dwellings or jobs per cell. Cells that are not fully developed in any given iteration are still available for future growth in subsequent iterations. The rate of 20 dwellings or jobs is used for the smallest five acre cell, and scaled up proportionately as cell size increases to the maximum of 100 acres. As shown in Figure 2, an important feature of the spatial allocation step is the model's re-running of the travel accessibility and infrastructure service ratings at the beginning of each interval year to account for changes in cell attractiveness as incremental growth causes those conditions to change over time.

14. *Tabulate final composite growth.* After a scenario has been fully distributed to its horizon year, the model sums and maps each year's final population, housing, employment, and travel characteristics.

15. *Measure sketch with indicators.* The model characterizes the sketch outcome by measuring the indicators listed in Section 3 for each interval year and the horizon year.

Figure 2
INTERVAL YEAR RECALCULATION OF CELL ATTRACTIVENESS



Interactions modeled:

A = Inter-period transportation system changes (added by user to GIS street coverage)
B = Inter-period land-use changes
C = Intra-period effects of land-use changes on travel patterns
D = Inter-period effects of travel and transportation system changes on land-use

Adapted from Southworth, 1995.

5. SNAPSHOT SKETCHES

This section describes the general modeling sequence for snapshot sketches. The basic operation allows entry of a "base case" scenario (representing either existing conditions in a developed area or an initial development proposal for an undeveloped area) and then gauging of potential impacts by varying:

- Land-use designations and densities.
- Mix of housing and jobs.
- Transportation system characteristics.

<u>Modeling Sequence</u>

1) *Sketch management.* The user initiates a parcel-based snapshot sketch by either: 1) opening an existing sketch; 2) creating an entirely new sketch; or 3) copying an existing sketch to create a new sketch with minor modifications that do not justify an entirely new sketch. Existing sketches may also be deleted at this point.

2) *Select sketch boundary.* The user selects any portion of the total area covered by the SGI database by either: 1) using a full layer from the database; 2) using a previous study boundary; or 3) selecting a set of features, e.g. a group of census tracts or TAZS.

3) *Specify scenario.* The user specifies a sketch scenario by selecting coverages from the database that must include, at a minimum: 1) parcels; 2) street centerlines; 3) land-use designations; 4) dwelling units by type; 5) non-residential uses by type and number of employees; and 6) transit stops. Scenarios can be assembled to represent existing conditions and various alternative development cases.

4) *Specify user-defined parameters.* The user is asked to set various parameters concerning land-use, transportation, and other resource conditions affecting a given scenario, including:

   - Regional and household population characteristics.
   - Household water and energy use, and pollutant emissions.
   - Locations of major activity nodes in the sketch area.

5. *Measure sketch with indicators.* The model scores the sketch outcome by measuring and mapping the indicators listed in Section 3.

Appendix A
TRANSPORTATION SUBMODEL

This appendix details the operation of SGI's transportation submodel. When operated in forecast sketching, the transportation submodel calculates travel accessibilities and indicator scores using a procedure similar to traditional four-step travel demand modeling, but stopping short of assigning trips to a street network.

When snapshot sketches are prepared, user-specified baseline VT and VMT values are adjusted by the submodel using elasticities that estimate VT and VMT change based on the amount of change in the sketch area's land-use density, diversity, and/or pedestrian design. This approach is used primarily for adjusting travel estimates produced by methods that are not otherwise sensitive to neighborhood urban form factors.

Forecast Sketches

The basic application of the submodel performs a simplified four-step transportation forecasting process based on user input. Trip generation and mode choice are based on national average rates for similar size urban areas from the Nationwide Personal Transportation Survey (NPTS), and are expressed as a function of household size and auto ownership.

Trip distribution (internal/ external split) is estimated based on a simplified gravity model, which compares the size and population level within the sketch area to the population within a 40-mile commute shed (sufficient to contain at least 95% of sketch area travel). In predicting the amount of travel that will remain internal to the sketch area, the trip distribution estimate accounts for the relative balances of housing with jobs, and housing with shopping and social/recreational opportunities (home-based-other trip balance). Users can obtain information on population and employment in their region from the US Census, or from their local metropolitan planning organization or council of governments.

Internal trip distribution is performed on a cell-by-cell basis using a gravity model. The model uses travel impedance curves (friction factors) from cities of similar size from NCHRP Report 365, Travel Estimating Techniques for Urban Planning, 1998, and links productions from a given cell to available attraction cells as a function of the relative magnitude of same-purpose attractions and the inverse of travel impedance to the attraction cells.

VMT and VHT are estimated based on trip lengths determined in the trip distribution estimate for internal and internal/external travel. Using national research by Texas Transportation Institute on congestion indices in urban areas, a simplified estimate of VHD is produced, based on VMT, urban area size, sketch area density, sketch area lane miles by class, and the user rating of sketch area congestion levels.

Beyond the basic application, the user has the option of enriching the analysis with local data as follows:

- *Local Household Profile*. The user can supply local information on household size and auto ownership to replace the national average default data. Local data will affect the model's prediction of household trip generation and mode choice based on NPTS relationships.

- *Mode Performance*. Under this enhancement, the user can test the impacts of changes in the relative performance of the drive alone, HOV, and transit modes. The user provides either real or hypothetical changes in relative modal travel times and costs. NCHRP-derived elasticity factors are used to predict the effects on mode choice and other indicators.

- *Background Traffic Counts*. Without baseline information on traffic volumes and general congestion levels within the sketch area, SGI has a limited sensitivity in estimating VHD changes between land-use alternatives. This enhancement allows the user to obtain improved VHD estimates by initializing the model with information on the existing amounts of traffic on sketch area freeways and arterials and the existing levels of congestion on a qualitative scale.

Trip Generation

<u>Step 1: Define Sketch Area</u>

a) User identifies the local urban area population size.

b) User identifies presence of any rail transit available in the region.

c) User estimates commuteshed population within 40 miles of edge of sketch area.

<u>Step 2: Create Household Auto Ownership Profile</u>

a) Produce profiles of household size and auto ownership for sketch area. SGI contains default values as shown in Table A-1 based on national data. The default matrices are displayed to the user, who may modify them as long as totals are controlled to 100%. Note that changes to the profiles of persons per household may alter the total sketch area population; users may wish to counterbalance such changes with compensating modifications in other household categories.

Table A-1
TYPICAL HOUSEHOLD PROFILES OF SIZE & AUTO OWNERSHIP

Urban Areas <50k Persons

# of vehicles	1-pers hh	2-pers hh	3-pers hh	4-pers hh	5+ pers hh	All hh
0	4.4%	1.4%	0.7%	0.5%	0.4%	7.4%
1	16.6%	11.3%	3.6%	2.5%	1.8%	35.8%
2	2.2%	17.9%	7.5%	6.6%	4.9%	39.1%
3+	0.4%	3.7%	5.1%	4.9%	3.6%	17.7%
All hh	23.6%	34.3%	16.9%	14.5%	10.7%	100.0%

Urban Areas 50k - 200k Persons

# of vehicles	1-pers hh	2-pers hh	3-pers hh	4-pers hh	5+ pers hh	All hh
0	4.5%	1.5%	0.7%	0.6%	0.5%	7.8%
1	16.5%	9.4%	3.5%	2.7%	2.0%	34.1%
2	2.2%	17.2%	7.5%	7.0%	5.1%	39.0%
3+	0.4%	3.6%	5.2%	5.6%	4.1%	18.9%
All hh	23.6%	31.7%	16.9%	15.9%	11.7%	99.8%

Urban Areas 200k - 500k Persons

# of vehicles	1-pers hh	2-pers hh	3-pers hh	4-pers hh	5+ pers hh	All hh
0	8.6%	3.1%	1.8%	1.7%	1.3%	16.5%
1	18.4%	9.9%	4.2%	3.7%	2.7%	38.9%
2	2.1%	13.9%	6.0%	5.5%	4.1%	31.6%
3+	0.4%	2.6%	3.6%	3.7%	2.8%	13.1%
All hh	29.5%	29.5%	15.6%	14.6%	10.9%	100.1%

Table A-1 *Continued*

Urban Areas 500k - 1000k Persons

# of vehicles	1-pers hh	2-pers hh	3-pers hh	4-pers hh	5+ pers hh	All hh
0	11.1%	4.6%	2.5%	2.2%	1.6%	22.0%
1	15.7%	9.9%	4.3%	3.2%	2.4%	35.5%
2	1.7%	12.5%	6.1%	5.4%	4.0%	29.7%
3+	0.3%	2.3%	3.5%	3.9%	2.8%	12.8%
All hh	28.8%	29.3%	16.4%	14.7%	10.8%	100.0%

Urban Areas 1000k+ Persons

# of vehicles	1-pers hh	2-pers hh	3-pers hh	4-pers hh	5+ pers hh	All hh
0	6.4%	2.6%	1.6%	1.8%	1.3%	13.7%
1	18.7%	8.5%	3.9%	4.1%	3.0%	38.2%
2	2.3%	15.1%	5.7%	5.7%	4.2%	33.0%
3+	0.4%	2.9%	4.0%	4.6%	3.4%	15.3%
All hh	27.8%	29.1%	15.2%	16.2%	11.9%	100.2%

Source: Adapted from U.S. Census

Step 3: Generate Production Trip Ends

a) The model multiplies cross-classified household data in each sketch area cell by rates developed in the Transportation Research Board NCHRP Report 365. Rates were developed for four ranges of urban population size as shown in Table A-2. The population determined in Step 1 above determines the appropriate rates to use. The result is the number of productions for each cell in the sketch area.

b) The model applies the following trip purpose percents to separate total productions for each sketch area cell into three trip purposes: home-based-work, home-based-other, and non-home-based:

HBW	20%
HBO	57%
NHB	23%

Non-home-based productions are not used, because the attraction calculations are considered to determine the level of NHB trips more accurately, and the location of non-NHB attractions determines the location of NHB productions, as described below in production and attraction balancing.

Step 4: Generate Attraction Trip Ends

The model calculates attraction trip ends using the following equations from NCHRP Report 365 for non-central business district areas to obtain the number of attractions for each trip purpose for each cell in the sketch area:

HBW Attr = 1.45 * Total Employment
HBO Attr = 9.00 * Retail Emp + 1.7 * Service Emp + 0.5 * Other Emp + 0.9 * Households
NHB Attr = 4.10 * Retail Emp + 1.2 * Service Emp + 0.5 * Other Emp + 1.1 * Households

NHB productions in each cell are calculated using the same formula given above for NHB attractions.

Table A-2
TRIP PRODUCTION RATES FOR SELECTED URBAN AREA POPULATIONS

Urbanized Area Pop 50,000 – 199,999						
	Persons/Household					
		1	2	3	4	5+
Autos Owned	0	2.6	4.8	7.4	9.2	11.2
	1	4.0	6.7	9.2	11.5	13.7
	2	4.0	8.1	10.6	13.3	16.7
	3+	4.0	8.4	11.9	15.1	18.0

Urbanized Area Pop 200,000 – 499,999						
	Persons/Household					
		1	2	3	4	5+
Autos Owned	0	2.1	4.0	6.0	7.0	8.0
	1	4.3	6.3	8.8	11.2	13.2
	2	4.3	7.5	10.6	13.0	15.4
	3+	4.3	7.5	13.0	15.3	18.3

Urbanized Area Pop 500,000 – 999,999						
	Persons/Household					
		1	2	3	4	5+
Autos Owned	0	2.5	4.4	5.6	6.9	8.2
	1	4.6	6.7	8.8	11.1	12.8
	2	4.6	7.8	10.4	13.0	15.4
	3+	4.6	7.8	12.1	14.6	17.2

Urbanized Area Pop 1,000,000+						
	Persons/Household					
		1	2	3	4	5+
Autos Owned	0	3.1	4.9	6.6	7.8	9.4
	1	4.6	6.7	8.2	10.5	12.5
	2	4.6	7.8	9.3	11.8	14.7
	3+	4.6	7.8	10.5	13.3	16.2

Mode Choice

Lookup matrices derived from the Nationwide Personal Transportation Survey are used to calculate percent auto driver, percent auto passenger, percent transit, and percent bike or walk on the basis of: urban size; rail availability; proximity to transit lines; trip purpose (work versus other); and household size and auto ownership (indirectly, through their effect on total person trip generation). Table A-3 provides the default mode choice percentages. Enhancement options include:

- *Household Profile Data*. The user can override the default values by inserting local auto ownership and family size information.

- *Mode Performance Factors*. The user may specify changes in the relative performance characteristics of transit, HOV and drive-alone modes on the following three factors:

  - In-Vehicle Travel Time (VTT), or time spent traveling within an auto, van, bus or train.

  - Out-of-Vehicle Travel Time (OVTT), or time spent walking to a parking spot or transit stop, or waiting for a carpool or transit vehicle.

  - Out-of-Pocket Cost (COST), which could include transit fare, auto operating cost, tolls or parking charges.

The model then calculates changes in modal utilities (U) based on these three factors, using the following relationships. It should be noted that other steps in the model, described later in this guide, account for shifts to non-motorized travel, including assessments of proximity to transit and the effects of land use characteristics.

U (auto) = [- 0.025 * VTT (auto)] + [-0.050 * OVTT (auto)] + [-.006 *COST (auto)]
U (hov) = [- 0.025 * VTT (hov)] + [-0.050 * OVTT (hov)] + [-.006 *COST (hov)]
U (tran) = [- 0.025 * VTT (tran)] + [-0.050 * OVTT (tran)] + [-.006 *COST (tran)]

The new mode shares for each mode are calculated by:

New Mode % = Old Mode % * exp U(mode) / $\text{sum}_{1..n}$ (Old Mode_n % * exp U(mode)_n),
where U is the change in utility and n is the number of modes.[1]

[1] See "Discrete Choice Analysis," Ben Akiva & Lerman, 1985, as reprinted in NCHRP Report 365, Travel Estimation Techniques for Urban Planning, 1998.

Table A-3
MODE CHOICE PERCENT LOOKUP
<1/4 Mile to Transit

< 1M Pop

	Work	Other
Driver	86.9%	63.7%
Auto Psgr	7.6%	33.2%
Transit	5.0%	1.9%
Walk/Bike	0.4%	1.2%
	100.0%	100.0%

1M+ Pop w/o Rail

	Work	Other
Driver	85.3%	63.2%
Auto Psgr	7.5%	33.0%
Transit	6.7%	2.5%
Walk/Bike	0.5%	1.3%
	100.0%	100.0%

1M+ Pop w/ Rail

	Work	Other
Driver	78.4%	60.4%
Auto Psgr	6.9%	31.6%
Transit	13.9%	5.4%
Walk/Bike	0.9%	2.6%
	100.0%	100.0%

Sources: Nationwide Personal Transportation Survey: 1990 NPTS Databook, Volume 1, page 4-75.
Ibid, page 4-78.
1990 NPTS Urban Travel Patterns, page 4-4.

Table A-3 *Continued*

MODE CHOICE PERCENT LOOKUP

1/4-1/2 Mile to Transit

< 1M Pop

	Work	Other
Driver	88.9%	64.4%
Auto Psgr	7.8%	33.6%
Transit	3.0%	1.1%
Walk/Bike	0.3%	0.8%
	100.0%	100.0%

1M+ Pop w/o Rail

	Work	Other
Driver	87.9%	64.1%
Auto Psgr	7.7%	33.5%
Transit	4.0%	1.5%
Walk/Bike	0.3%	0.9%
	100.0%	100.0%

1M+ Pop w/ Rail

	Work	Other
Driver	83.4%	62.4%
Auto Psgr	7.3%	32.6%
Transit	8.6%	3.2%
Walk/Bike	0.6%	1.8%
	100.0%	100.0%

Sources: Nationwide Personal Transportation Survey: 1990 NPTS Databook, Volume 1, page 4-75.
Ibid, page 4-78.
1990 NPTS Urban Travel Patterns, page 4-4.

Table A-3 *Continued*

MODE CHOICE PERCENT LOOKUP

½+ Mile to Transit

< 1M Pop

	Work	Other
Driver	90.4%	64.9%
Auto Psgr	7.9%	33.9%
Transit	1.5%	0.5%
Walk/Bike	0.3%	0.7%
	100.0%	100.0%

1M+ Pop w/o Rail

	Work	Other
Driver	89.9%	64.7%
Auto Psgr	7.9%	33.8%
Transit	2.0%	0.7%
Walk/Bike	0.3%	0.7%
	100.0%	100.0%

1M+ Pop w/ Rail

	Work	Other
Driver	87.4%	63.7%
Auto Psgr	7.7%	33.2%
Transit	4.4%	1.6%
Walk/Bike	0.6%	1.5%
	100.0%	100.0%

Sources: Nationwide Personal Transportation Survey: 1990 NPTS Databook, Volume 1, page 4-75.
Ibid, page 4-78.
1990 NPTS Urban Travel Patterns, page 4-4.

External Trip Distribution

The external trip distribution step is run following trip generation and mode split to compute the number of trips that leave the sketch area (I-X or X-I trips), excluding through trips. Some of the results of calculations in this process are also used in the subsequent process, which distributes travel staying completely inside the sketch area (I-I trips). References below to productions, attractions, or trips mean the auto mode, as trip distribution processes apply only to auto travel.

Step 1: Calculate Travel Distances Internal to Sketch Area

Calculate the straight-line distance between the centers of each pair of cells i and j in the sketch area and store the result in row i, column j, in the travel distance matrix. Calculate each diagonal matrix-cell (where i = j) as the average straight-line distance from any point within the cell to the cell perimeter. This is used as the average distance for trips made entirely within the corresponding geographic cell (intra-cell trips).

Step 2: Calculate Average Distances Between Internal and External Trip Ends and Sketch Area Perimeter

SGI calculates the average straight-line distance from sketch area cells to the sketch area perimeter. The average distance of the external portion of a trip between the sketch area and the 40-mile outside commuteshed is then calculated. Based on an examination of Census journey-to-work data for a full range of US urban areas, the 40-mile radius captures about 98% of all commuting from a trip source-point. Therefore, the analysis uses this cut-off as a means of keeping the study region size manageable without excluding a significant amount of travel. The average extent of a trip into the 40-mile commuteshed is a function of the size of the sketch area relative to the size of the commuteshed. SGI makes the simplifying assumption that commuteshed population and employment are uniformly distributed within the commuteshed.

Step 3: Calculate Friction Factors

The term “cell” in this step refers to a sketch area cell or to the area of the commuteshed outside the sketch area (this external area as a whole is represented as one row and column in the matrices developed here). SGI assigns “terminal impedance” values to each cell, to represent the cost and time associated with beginning and ending a trip (for example, the time required to park a car, or to walk to or from a transit stop). The impedances apply to motorized trips; other steps in the model account for shifts to non-motorized travel, including assessments of proximity to transit and the effects of land use characteristics. These terminal impedances are expressed in minutes and vary by area type. SGI determines a cell's terminal impedance based on the following information from NCHRP Report 365:

Area type	Terminal Impedance
CBD	5
CBD Fringe	4
Urban	3
Suburban	2
Exurban/Rural	1

The friction factor between each pair of cells is calculated as:

$$d_{ij} = a_{ij} * net_i$$
$$t_{ij} = d_{ij} / [v(d_{ij})/60] + T_i + T_j$$
$$F_{ij} = (t_{ij})^b * e^{ct_{ij}}$$

Where:

d_{ij} = network distance from cell i to j
a_{ij} = straight-line distance from cell i to j
net_i = network directness adjustment factor for zone i (based on sample of five destinations)
t_{ij} = travel-time impedance from cell i to j in minutes
$v(d_{ij})$ = average travel speed which varies as a function of distance
T_i, T_j = terminal impedance for cells i and j
F_{ij} = friction factor between cells i and j
b, c = model coefficients from NCHRP Report 365
e = base of natural logarithms

Model coefficients from NCHRP are:

Trip Purpose	b	c
HBW	-0.020	-0.123
HBO	-1.285	-0.094
NHB	-1.332	-0.100

Step 4: Calculate Productions and Attractions for Area Outside Sketch Area

SGI performs the following procedure for each trip purpose. In the trip generation process, productions and attractions were calculated for each cell in the sketch area. Total productions for the area outside are now calculated as:

$$P_X = P_I * \frac{Pop_X}{Pop_I}$$

where P_X = Productions generated in external area
P_I = Productions generated in sketch area (from trip generation step)
Pop_X = Population of external area
Pop_I = Population of sketch area

Total external area attractions are calculated as:

$$A_X = P_I + P_X - A_I$$

where A_X = Attractions generated in external area
A_I = Attractions generated in sketch area
P_X = Productions generated in external area
P_I = Productions generated in sketch area

This produces the number of outside attractions required so that overall productions and attractions are equal (”balanced”).

Step 5: Calculate Travel Staying Within Sketch Area

SGI performs the following procedure for each trip purpose:

$$\%P = \frac{A_I * F(D_{II})}{A_I * F(D_{II}) + A_X * F(D_I + D_X)}$$

$$P_{II} = \text{Min}\,[\,(P_I * \%P),\,(0.95 * A_I)\,]$$

$$A_{II} = P_{II}$$

$$\%A = A_{II} / A_I$$

where $\%P$ = Percent of any cell’s productions used for internal trips
$\%A$ = Percent of any cell’s attractions used for internal trips
P_{II} = Productions generated by all cells in sketch area for trips within sketch area

A_{II}	=	Attractions generated by all cells in sketch area for trips within sketch area
P_I	=	Productions generated by all cells in sketch area for internal and external travel
A_I	=	Attractions generated by all cells in sketch area for internal and external travel
A_X	=	Attractions generated in external area
F( )	=	Friction factor calculated as shown in Step 3
D_I	=	Avg straight-line distance through sketch area for external trips
D_X	=	Avg straight-line distance through outside area for external trips
D_{II}	=	Avg straight-line distance between all pairs of internal cells

%P and %A are used in the current process and stored for use in sketch area trip distribution.

Step 6: Distribute External Travel

SGI performs the following procedure for each trip purpose. For each cell, trips between its productions and the external area as (1- %P) x total productions generated in the cell are calculated. The result is placed in the appropriate purpose trip table in the matrix-cell where the cell's row intersects the external area column. Also for each cell, trips between its attractions and the external area as (1 - %A) x total attractions generated in the cell are calculated. The result is placed in the appropriate purpose trip table in the matrix-cell where the cell's column intersects the external area row.

Internal Trip Distribution

Step 1: Calculate Number of Trips Staying Within Sketch Area

SGI performs the following procedures for each trip purpose. For each cell in the sketch area, apply the internal productions percent (%P) calculated previously to the total productions generated in the cell to get internal travel productions for distribution below. For each cell in the sketch area, apply the internal attractions percent (%A) calculated previously to the total attractions generated in the cell to get internal travel attractions for distribution below.

Step 2: Distribute Internal Trips Using Gravity Model

SGI performs the following procedure for each trip purpose. It calculates the number of trips from each cell to each other cell as:

$$T_{ij} = P_i \times \frac{A_j F_{ij}}{\sum_{k=1}^{cells} A_k F_{ik}}$$

where	T_{ij}	=	number of trips from cell i to cell j
	P_i	=	productions in cell i for trips within sketch area
	A_j	=	attractions in cell j for trips within sketch area
	F_{ij}	=	friction factor between cells i and j (calculated and stored previously)

At the completion of this step, each purpose trip table contains the internal external trips calculated and stored previously.

Step 3: Balance the Trip Tables

The model interactively balances each purpose trip table so that the number of distributed productions and attractions for each cell approximates the productions and attractions generated in the cell. First, the number of trips in each column is summed, and the ratio of that sum to the attractions generated in the cell corresponding to the column is calculated. Then the cells in the column are factored by that ratio. After completing all columns of the trip table, the same process is applied to the trip table row-wise. Three iterations are performed (3 row adjustments and 3 column adjustments), with the final adjustment performed on the rows.

Step 4: Combine Trip Tables for All Purposes to Produce Total Table of All Trips Generated in Sketch Area

Steps 1-3 above produce three trip tables (HBW, HBO, and NHB), each containing the internal trips (I-I) calculated above, and the external trips (I-X and X-I) calculated previously. These three tables are added together, cell by cell, to produce one total trip table of all trips generated in the sketch area.

Trip Length

Ratios of roadway distance to airline distance are calculated by building shortest roadway paths on the GIS street centerline network from each cell centroid to five points: one point each on the north, south, east, and west sides of the sketch area perimeter, plus the sketch area centroid. These same five points are used for each cell. For each path, the program keeps track of local street, arterial, and freeway miles separately. The five sets of results for each cell are averaged, and three ratios are calculated for the cell: local street, arterial, and freeway miles to airline miles. These ratios are stored in a matrix having one row for each cell, and one column each for the local street, arterial, and freeway ratios. In the following step, each matrix-cell in the airline distance matrix, including the column for the area outside the sketch area but excluding the row for the external area, is multiplied by the value in the corresponding row and the local streets column of the distance ratios matrix. This produces the local streets distance matrix except the row for the external area. This row is produced as the transpose of the external area column. The result is a local street miles matrix with the same dimensions as the airline distance matrix. Matrices for arterial and freeway distance are produced similarly. The three roadway distance matrices will provide cell-to-cell and cell-to-external-area mileage for local street, arterial, and freeway travel. Subsequently, the values in these matrices are multiplied by the numbers of trips in the corresponding matrix-cells of the total trip table to calculate roadway VMT. For enhancement purposes, the trip length matrices can be factored by the adjustment matrix derived from the selected research findings on land-use/travel demand relationships.

Vehicle Hours of Travel and Delay

Vehicle hours of travel (VHT) are calculated from vehicle miles (VMT), based on national research in the Texas Transportation Institute (TTI) Urban Mobility Study. Statistical analysis of 1996 data for 70 urban areas yields the following equations:

VF = 77.5 - 29.3 * RCI (R-square = 0.79, t = 15.8)
VA = 34.5 - 5.3 * RCI (R-square = 0.32, t = 5.6)

Where:
VF = Average peak period freeway speed
VA = Average peak period arterial speed
RCI = Roadway Congestion INDEX = ((Freeway VMT/Freeway Lane Miles) * Freeway VMT + (Arterial VMT/Arterial Lane Miles) * Arterial VMT) / (13,000 * Freeway VMT + 5,000 * Arterial VMT)

In the above formulas, arterial VMT and freeway VMT both represent peak hour vehicle miles on the respective systems. The peak hour VMTs are calculated from average daily VMT computed in previous sections by use of the following factors from NCHRP 365:

Urban Area Size	Peak Hour VMT % of Daily
50,000 – 199,999	9%
200,000 and above	9.5%

The resulting speeds are divided into the VMT estimates to obtain VHT estimates. Vehicle hours of delay (VHD) are calculated by comparing the resulting congestion-influenced VHT estimates to free-flow VHT (derived by assuming free-flow speeds of 60 mph for freeways and 35 mph for arterials). The difference between congestion-influenced VHT and free-flow VHT is the study area's VHD. The above calculations can be calibrated to match the user's perception of congestion and delay. The calculated change in highway speed from the TTI formula is then used to estimate the future change from the user's perception of the base year congestion level. For example, if the TTI VF for the base year is 39 mph (corresponding to the user's 36.5 estimate) and the VF for the future case is estimated to be 30 mph, then the future freeway speed, calibrated for user perception, would be:

$$\text{Calibrated Future VF} = 30/39 * (36.5) \text{ mph}$$

A similar process can be applied for the user's perception of the condition of the arterial street system to calibrate the future VA estimate used for VHT and VHD. Trip length calculations (VMT) include local street travel within the sketch study area. Like most four-step models, SGI assumes that local collector and neighborhood streets are uncongested.

Snapshot Sketches

When snapshot sketches are prepared, the transportation submodel applies a set of elasticities to user-defined baseline VT and VMT values to estimate changes in VT and VMT resulting from changes in land-use density, diversity, and/or pedestrian design. The elasticities are based on a review and synthesis of research itemized in Appendix B. Data and findings from 27 of the most relevant studies were compiled for this synthesis. Because several of the 27 studies represent updates or enhancements of earlier studies by the same authors, the data effectively represent the findings of about 32 of the documents listed in the full Appendix B bibliography. By synthesizing the results of these studies, it was possible to produce transferable formulae that predict proportional changes in travel relative to key land-use variables.

These key variables, the urban form characteristics known as the "3Ds" (density, diversity, and design), were studied individually and in different combinations in order to isolate their respective effects. The synthesis includes much of the best empirical research on impacts of the built environment on travel behavior, and attempts to account for cases where sensitivities differ across studies. The approach consisted of the following steps:

- Elasticities were derived between vehicular travel (VT and VMT) and primary descriptors of the built environment (the 3Ds) based on reputable studies.

- The results were synthesized into a unified matrix of partial elasticities. The elasticities express the percentage changes in VT and VMT as a function of percentage changes in each of the 3Ds.

The 3Ds are expressed in terms of land-use factors, including population and employment per square mile (density), ratio between jobs and population (diversity), and pedestrian environment variables of street network density, sidewalk completeness, and route directness (design).

- A table of elasticities was produced for assessing the relative benefits of one land-use pattern compared with another.

These elasticities are believed to advance the state-of-the-art for quick response sketch methods in the following respects:

- They include a larger number and wider range of research studies than previous syntheses, including recent studies in Portland (Sun, Lawton, PBQD), Seattle (Hess) and the San Francisco Bay Area (Cervero, Kockelman, Holtzclaw). These three were tightly controlled and statistically sophisticated.

- One of the research studies directly measures pedestrian travel through counts of pedestrian volumes entering commercial centers, whereas most studies rely on household or workplace questionnaires which are known to under-report walk travel.

- An "accessibility" factor is introduced to account for the fact that a given set of urban form characteristics (density, diversity, design) will not produce the same effects on travel behavior in remote areas surrounded by typical suburban neighborhoods as they will at centrally-located urban infill locations. Several studies (including the research on which LUTRAQ is based) have demonstrated that the effects of the 3Ds on travel are weaker in outlying areas than infill areas, even if the areas are similar in other respects, such as transit service and average household income. When used in regionwide analysis, the accessibility factor also enables the analysis to recognize the benefits of placing development near transportation corridors, and at locations that are centrally located relative to compatible activities. The factor allows the analysis to reflect the benefit, for example, of siting commercial development proximate to transit, or at locations convenient to the greatest number of residents. The elasticities presented in Table 2 distinguish the effects of regional accessibility from the 3Ds.

Application of the Results

The values presented in Table A-4 show the elasticities that result when the 3Ds are used as independent variables, and also distinguishes the effects of regional accessibility from the 3Ds. As shown, accessibility accounts for a significant portion of travel demand sensitivity to land-use variables, and the individual effects of the 3Ds are proportionally reduced. The 3D elasticities are applied in SGI if a travel demand forecasting model has already been used to account for baseline differences in travel demand as a function of accessibility. The accessibility elasticity is not applied as part of the SGI modeling process, but is shown in Table A-4 so the user can understand how much of the effect on VT and VMT can be attributable to differences in regional accessibility.

In summary, SGI applies the 3D elasticities as follows:

1. Computes the percentage change in each of the 3D variables that is expected to occur under the proposed land-use scenario (see the variable definitions in the notes to Tables A-4 for guidance). If the sketch area is greater than two miles in diameter, it is recommended that the sketch area's density, diversity and design be measured by sampling these variables within two-mile subareas of the larger sketch area, and calculating an average.

2. Applies the elasticity value for density to the computed percentage change in sketch area density, to obtain the percentage change in VT per capita and VMT per capita as a result of the density change. Similarly, computes the percentage changes in VT and VMT per capita resulting from the percentage changes in diversity and design.

3. Sums the individual travel change percentages for all three of the 3D's to obtain the total percentage change in VT and VMT per capita resulting from the change in sketch area density, diversity and design.

This procedure assumes that sketch area demographics (household size and autos per household), transit levels of service, travel prices, and travel times on major corridors do not change from one design case to another.

Limitations and Considerations in Applying the Method

The following considerations are important to successful application of the 3D elasticities method:

- *Regional or Multi-Site Analysis*

  The following method should be used for comparison of growth scenarios for an entire region or for multiple development sites scattered throughout a region. Regional analysis includes comprehensive assessments of development patterns over a large, relatively homogeneous area, or a large area consisting of multiple communities. Growth scenarios can be comparisons of existing versus future conditions, or comparisons of "trends" versus "smart growth," or comparisons of several plan alternatives. Regional analysis methods will generally be used for areas of 25 square miles or greater. Multi-site analysis refers to analyses that attempt to compare the effects of allocating growth to one site within the region versus others. Sites would differ with respect to one or more of the following: 1) their degree of centralization, 2) their distance to jobs and housing, 3) their context within the urban fabric (infill within a dense area versus an edge or suburban setting), and/or 4) their proximity to transportation facilities. The preferred approach to regional and multi-site analysis is to use data from the regional 4-step model for baseline VT and VMT generation rates for each individual geographic unit within the region. The VT and VMT rates should be for the forecast year under study, so that the relevant transportation network characteristics are reflected in the accessibility measure for each geographic unit and affect the geographic unit trip rates. If the comparison is being made between two different forecast years, each year should be represented via 4-step data. The VT and VMT should each be expressed as:

- ☐ Vehicle Trips per Resident: HBP VT / Population
- ☐ Vehicle Trips per Employee: NHA VT / Employment

- ☐ Vehicle Miles per Resident: HBP VMT / Population
- ☐ Vehicle Miles per Employee: NHA VMT / Employment

These rates can be obtained by taking the appropriate ratios among the zonal population, employment, home-based vehicle trips produced (HBP), and non-home-based vehicle trips attracted (NHA) for the model TAZ that includes the geographic unit. The advantages of this approach include: 1) multiple regional development patterns can be tested, without running the 4-step for each case; 2) regional land-use form can be reflected (the effects of intensifying land use in infill versus greenfield locations) and measured along with the effects of design, density and diversity within each development area; and 3) the evaluation of land-use alternatives can be sensitive to the proximity of growth to regional transportation facilities, including fixed transit corridors. If the foregoing preferred technique is not feasible, the following less-robust options may be used instead: measure regional accessibility of each geographic unit using the 4-step gravity model, using the accessibility formula given in the notes to Table A-4, then apply the full set of elasticities from Table A-4 to density, diversity, design, and accessibility.

- *Individual Site Analysis*

When the 3D methodology is being applied to evaluate different project designs at the same development site, a simpler approach is possible than the regional or multi-site technique. For single-site analyses, the procedure is: 1) obtain an estimate of current VT and VMT per capita from local household surveys or regional model estimates. If those sources are not available, Census data can be used as a surrogate for the site's relative VT and VMT per capita compared with the regional average, using the assumption that the relationship between work trips and total trips for the sub-area is the same as for the region. If the regional relationship between work trips and total trips is not known, the user can expand Census-based work trip data to total trips by applying a factor of 4 for VT and a factor of 4 for VMT.[a] The data should represent the census tract or TAZ in which the site lies, if areas of the tract or TAZ are already urbanized. If the immediate site area is underdeveloped or vacant, VT and VMT rates from a nearby tract or TAZ should be used instead. The area used as a comparable should already be urbanized and should have similar levels of income and transit availability to the subject site; 2) apply the 3D elasticities from Table A-4 to the alternate site design characteristics to measure the changes in VT and VMT per capita. Do not apply the accessibility elasticity, which is provided for informational purposes only.

- *Size and Homogeneity of Sketch Areas*

The sketch areas to which the 3D elasticities are applied should be less than two miles in diameter (about 2,000 acres). If larger areas are under study, density, diversity and design should be sampled within two-mile sub-areas of the larger sketch area, and the results averaged to obtain the geographic unit's ratings for these independent variables. This is because the effects of the 3Ds on reduction of auto travel and trip length are primarily due to the proximity of interactive and well-designed uses to one another and the opportunity this provides for walk and bicycle travel between them. For example, a large area with employment

[a] Calculated from information provided in NCHRP Report 365, Travel Estimation Techniques for Urban Planning, 1998. For VT: HBW trips are shown to represent 20-22% of daily person trips. Because auto occupancies are lower for HBW trips than for other trip types, we estimate that HBW trips constitute roughly 25% of daily vehicle trips. For VMT: Non-work trip times are shown to be 60-85% of HBW trip times, depending on urban area size. Non-work trips are more likely to occur during off-peak periods, when uncongested conditions allow travel of greater distances per unit time. We estimate that average non-work trip distances are roughly 75% of work trip distances, resulting in a work trip VMT-to-total trip VMT ratio of 4:1.

Table A-4
TRAVEL ELASTICITIES OF
DENSITY, DIVERSITY, DESIGN
AFTER ACCOUNTING FOR RELATIVE REGIONAL ACCESSIBILITY

	Vehicle Trips$_{total}$	**VMT$_{total}$**
Density	-0.043	-0.035
Diversity	-0.051	-0.032
Design	-0.031	-0.039

Accessibility	-0.036	-0.204

Table A-4 *Continued*
DEFINITIONS

Density = Percent Change in [(Population + Employment) per total Square Mile]

Diversity = Percent Change in {1 - [ABS(b * population - employment) / (b * population + employment)]}

where: *b* = regional employment/regional population

Design *either* = Percent Change in locally-calibrated Pedestrian Environment Factor (PEF)

or = Percent Change in Design INDEX (see below)

Design INDEX = 0.0195 * street network density + 1.18 * sidewalk completeness + 3.63 * route directness

where:

street network density = length of street in miles/area of neighborhood in square miles

sidewalk completeness = length of sidewalk/length of public street frontage

route directness = average airline distance to the neighborhood center/average road distance to the neighborhood center

Accessibility = Percent Change in Gravity Model denominator for study TAZ's "i": Sum[Attractions(j)*Travel Impedance(i,j)] for all regional TAZ's "j" clustered at one end and residential uses at the other should not be considered as diverse as an area with block-by-block mixing of land uses. Therefore, this sampling and averaging technique is recommended to better capture the 3D effects in large study areas. This recommendation does not restrict the application of the 3D method overall, but it simply provides sufficient detail to detect neighborhood- or community-level urban form. Users should not allow undeveloped areas within a geographic unit to dilute the calculated density unless the undeveloped area lies within the active areas, lengthening the travel distance for those traveling from one point to another within the active area. Open acreage on the edge of the geographic unit should not be counted in the density calculation.

- *Effects of Other Variables*

There are undoubtedly other variables not discussed here that may have an effect on travel behavior. For instance, some experts include the effects of topography, climate and culture when describing the likelihood of substituting walk or bicycle trips for motorized trips. None of the research studies consulted for this synthesis measured the effects of these variables on vehicle trips and VMT. SGI is intended to predict relative changes in VT and VMT for land use changes in a given urban area. Users should be cautious when comparing results from one urban area to another, particularly where those areas exhibit significant differences in topography, climate, or other variables that might be related to the choice of motorized vs. non-motorized travel.

Opportunities for Further Review and Enhancement

- *Potential Relationships Among Independent Variables*

The 3D descriptors of the built environment may be highly correlated with one another. For example, the densest environments (namely CBDs) also tend to have mixed land uses and pedestrian-friendly streets. Every effort was made to reduce the extent of potential collinearity within the bounds of the available research. Documents that reported multi-factor analysis and/or that exercised controls over potentially correlated variables were given the greatest weight in the synthesis. Since few, if any, of the original research studies fully excluded collinear bias for all of the 3Ds, some degree of collinearity may well remain among certain variable combinations in the final 3D elasticities.

Similarly, density may be correlated with accessibility, in that dense environments are more likely to be located in central areas with good transit services. It does appear that high-accessibility (infill) locations enjoy greater travel-reduction benefits from dense, diverse and/or well-designed urban forms than do remote locations. In the 3D method, elasticities from the

Table A-4 use regional accessibility as a means of accounting for the additional reductions in VT and VMT found in centrally located, well-connected areas.

Further research on the 3D variables, individually and in combination, as well as additional analysis of different combinations of potentially correlated variables such as urban context, accessibility and transit proximity, may help clarify these relationships and improve the 3D elasticities.

■ *Apparent Anomalies in 3D Results*

The current 3D elasticities are based on a wide array of primary research studies. Some of the studies in Appendix B show results that disagree with one another. As a result of these disagreements, the resulting elasticities exhibit some apparent anomalies. For example, many experts may expect that the elasticity of VMT with respect to design should be lower than the elasticity of VT with respect to design. This is because many believe that the biggest impact of good design is to convert short-distance auto trips to walk or bike trips, while longer distance auto trips might not be affected by good neighborhood design. Current elasticity results show a higher relationship for VMT than for VT. This is because, even though one of the reference studies indicated that the VMT elasticity should be lower than the VT elasticity, several other reputable studies disagreed. The LUTRAQ study, for example, found an elasticity of VMT to design significantly higher than the result of our synthesis. Two other studies found VMT/design elasticities very close to our result and higher than our resultant VT/design elasticity. Therefore, the preponderance of empirical data available to the 3D synthesis suggests that good design reduces not only the amount of vehicle trip-making, but the average length of vehicle trips as well. While this may be counter-intuitive to some, the conventional wisdom on how the VMT and VT rates “should” compare with one another may not take into consideration the following phenomena:

- ☐ The effects of self-selection, that is, individuals who move to well-designed neighborhoods may have a pre-disposition to drive less for trips of any length.

- ☐ Developments that score high on the design iNDEX are often at infill locations nearer to a greater proportion of regional jobs and housing; therefore, average trip lengths may be shorter.

- ☐ Developments that score high on the design iNDEX are often at locations nearer to high-quality transit service than are locations with poorer design indices; therefore, residents of high-design neighborhoods may have better non-auto choices even for their longer trips than do residents of low-design neighborhoods.

Similarly, the 3D synthesis found that diversity had a slightly stronger bearing on travel than does density. While density is generally considered the strongest land-use determinant of travel behavior, two of the most highly-regarded sources (Cervero, 1999 and Frank/Pivo, 1994) found that diversity exercised greater influence on VT than did density. One possible explanation is that density without diversity reduces travel less than does diversity without density. Further research, using additional household survey data, could clarify this phenomenon and otherwise improve the 3D elasticities.

Interpretation of VMT and VT Per Capita

Planners often use global transportation indicators such as vehicle trips (VT) or vehicle miles of travel (VMT) per capita to compare the travel impacts of one plan to another. These indicators are usually extracted at a regional scale from household census, home interview travel diary data, or from scans of regional roadway traffic count data or Department of Motor Vehicle odometer data. While effective at a regional scale, VT and VMT per capita become much less reliable when used at sub-area level, because many of the trips and vehicle miles are not related to the population of the sub-area, but rather to the number of jobs or shopping opportunities located within the sub-area. Therefore, dividing the sub-area's total generated VT or VMT by its population provides an erroneous indicator of VT or VMT per capita. VT per capita for a commercial core, for example, would be exorbitantly large, due to the large number of trips generated by core businesses compared with the low resident population. Therefore, SGI uses disaggregate indicators to quantify the travel behavior occurring within a sketch area:

- Home-Based-Productions (HBP); and

- Non-Home-Attractions (NHA), which includes both home-based attractions (HBA) and non-home-based trips (NHB).

To help understand these indicators in a regional context, it is useful to understand the normal relationships between these sub-area indicators and the more familiar regional VMT and VT per capita. Typically, the following percentages of regional VT per capita fall into each of the disaggregate categories:

Home-Based Productions (HBP) . . . . 40% of regional VT/Capita
Home-Based Attractions (HBA) . . . . 40% of regional VT/Capita
Non-Home-Based (NHB) . . . . 20% of regional VT/Capita

Similarly, regional VMT per capita obeys roughly the following breakdown when viewed at the disaggregate level:

Home-Based Productions (HBP) . . . . 42% of regional VT/Capita
Home-Based Attractions (HBA) . . . . 42% of regional VT/Capita
Non-Home-Based (NHB) . . . . 16% of regional VT/Capita

Therefore, in a region with an average VT of 20 per capita, one would expect a regional average of roughly 8 VT per capita 40% produced at home (HBP). Trips both directly and indirectly associated with the location and design of the population-based environment (HBP and HBA trips combined) would equal 80% of the total regional VT/Capita or about 16 trips per capita. A plan for a sub-area which would otherwise generate at the regional-average 8 VT per capita (HBP), but which adds density, diversity, and design characteristics sufficient to reduce a sub-area to 6 VT per capita (HBP) will have reduced that sub-area's VT per capita by 25%.

Appendix B
BIBLIOGRAPHY OF TRAVEL STUDIES USED IN "3D" METHODOLOGY

Studies Included in Statistical Analysis

1. Buch, M. and M. Hickman (1999) "The Link Between Land Use and Transit: Recent Experience in Dallas," paper presented at the 78th Annual Meeting, Transportation Research Board, Washington, D.C.

2. Cambridge Systematics, Inc. (1994) *The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior*, Technology Sharing Program, U.S. Department of Transportation, Washington, D.C., pp. 3-1 through 3-25.

3. Cervero, R. (1991) "Land Use and Travel at Suburban Activity Centers," *Transportation Quarterly*, Vol. 45, pp. 479-491.

4. Cervero, R. (1996) "Mixed Land-Uses and Commuting: Evidence from the American Housing Survey," *Transportation Research A*, Vol. 30, pp. 361-377.

5. Cervero, R. (1999) Unpublished aggregated database of neighborhood land use and travel characteristics for the San Francisco Bay Area. Fehr & Peers conducted expanded analysis of this database.

6. Cervero, R. and R. Gorham (1995) "Commuting in Transit Versus Automobile Neighborhoods," *Journal of the American Planning Association*, Vol. 61, pp. 210-225.

7. Cervero, R. and K. Kockelman (1997) "Travel Demand and the 3Ds: Density, Diversity, and Design," *Transportation Research D*, Vol. 2, pp. 199-219.

8. Cervero, R. and C. Radisch (1996) "Travel Choices in Pedestrian Versus Automobile Oriented Neighborhoods," *Transport Policy*, Vol. 3, pp. 127-141.

9. Dunphy, R.T. and K. Fisher (1996) "Transportation, Congestion, and Density: New Insights," *Transportation Research Record 1552*, pp. 89-96.

10. Ewing, R. (1995) "Beyond Density, Mode Choice, and Single-Purpose Trips," *Transportation Quarterly*, Vol. 49, pp. 15-24.

11. Ewing, R. (1999) Fehr & Peers conducted expanded analysis of Dade County and Palm Beach County databases from this author.

12. Ewing, R., M. DeAnna, and S. Li (1996) "Land Use Impacts on Trip Generation Rates," *Transportation Research Record 1518*, pp. 1-7. (Data reanalyzed by Fehr & Peers, citation 11 above)

13. Frank, L.D. and G. Pivo (1994b) *Relationships Between Land Use and Travel Behavior in the Puget Sound Region*, Washington State Department of Transportation, Seattle, pp. 9-37.

14. Handy, S. (1993) “Regional Versus Local Accessibility: Implications for Non-Work Travel,” *Transportation Research Record 1400*, pp. 58-66.

15. Handy, S. (1996) “Urban Form and Pedestrian Choices: Study of Austin Neighborhoods,” *Transportation Research Record 1552*, pp. 135-144.

16. Hess, P.M., et al. (1999) “Neighborhood Site Design and Pedestrian Travel,” paper presented at the Annual Meeting of the Association of Collegiate Schools of Planning, American Planning Association, Chicago.

17. Holtzclaw, J. (1994) *Using Residential Patterns and Transit to Decrease Auto Dependence and Costs*, Natural Resources Defense Council, San Francisco, pp. 16-23.

18. Kockelman, K.M. (1997) “Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area,” paper presented at the 76th Annual Meeting, Transportation Research Board, Washington, D.C.

19. Lawton, K. (1998) “Travel Behavior – Some Interesting Viewpoints,” paper presented at the Portland Transportation Summit, Portland Metro.

20. McNally, M.G. and A. Kulkarni (1997) “An Assessment of the Land Use-Transportation System and Travel Behavior,” paper presented at the 76th Annual Meeting, Transportation Research Board, Washington, D.C. (Fehr & Peers conducted expanded analysis of database, 1999)

21. McNally, M.G. and A. Kulkarni (1999) Fehr & Peers conducted expanded analysis of database from citation 20 above.

22. Noland, R.B. and W.A. Cowart (1999) “Analysis of Metropolitan Highway Capacity and the Growth in Vehicle Miles of Travel,” paper submitted for presentation at the 79th Annual Meeting, Transportation Research Board, Washington, D.C.

23. Parsons Brinckerhoff Quade Douglas (1993) *The Pedestrian Environment*, 1000 Friends of Oregon, Portland, pp. 29-34.

24. Parsons Brinckerhoff Quade Douglas (1994) *Building Orientation - A Supplement to "The Pedestrian Environment*," 1000 Friends of Oregon, Portland, pp. 9-14.

25. Rutherford, G.S., E. McCormack, and M. Wilkinson (1996) “Travel Impacts of Urban Form: Implications From an Analysis of Two Seattle Area Travel Diaries,” TMIP Conference on Urban Design, Telecommuting, and Travel Behavior, Federal Highway Adminstration, Washington, D.C.

26. Schimek, P. (1996) “Household Motor Vehicle Ownership and Use: How Much Does Residential Density Matter?” *Transportation Research Record 1552*, pp. 120-125.

27. Sun, X., C.G. Wilmot, and T. Kasturi (1998) “Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Travel Survey,” paper presented at the 77th Annual Meeting, Transportation Research Board, Washington, D.C.

Studies Included Indirectly in Statistical Analysis through Inclusion of Subsequent Updates

1. Ewing, R., P. Haliyur, and G.W. Page (1994) "Getting Around a Traditional City, a Suburban PUD, and Everything In-Between," *Transportation Research Record 1466*, pp. 53-62.

2. Frank, L.D. and G. Pivo (1994a) "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking," *Transportation Research Record 1466*, pp. 44-52.

3. Kulkarni, A., R. Wang, and M.G. McNally (1995) "Variation of Travel Behavior in Alternative Network and Land Use Structures," *ITE 1995 Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., pp. 372-375.

4. Moudon, A.V. et al. (1997) "Effects of Site Design on Pedestrian Travel in Mixed-Use, Medium-Density Environments," paper presented at the 76th Annual Meeting, Transportation Research Board, Washington, D.C.

5. Suhrbier, J.H., S.J. Moses, and E. Paquette (1995) "The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior," *ITE 1995 Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., pp. 367-371.

Studies Not Included in Statistical Analysis

1. Boarnet, M. and R. Crane (1999) *Travel by Design – The Influence of Urban Form on Travel*, Oxford University Press, New York, Chapter 5.

   Lack of data needed to calculate elasticities.

2. Cervero, R. (1988) "Land Use Mixing and Suburban Mobility," *Transportation Quarterly*, Vol. 42, pp. 429-446.

   Similar but less relevant than same author's 1991 study of suburban activity centers.

3. Cervero, R. (1989) *America's Suburban Centers - The Land Use-Transportation Link*, Unwin Hyman, Boston, pp. 137-142.

   Similar but less relevant than same author's 1991 study of suburban activity centers.

4. Cervero, R. (1994b) "Rail-Oriented Office Development in California: How Successful?" *Transportation Quarterly*, Vol. 48, pp. 33-44.

   Lack of data needed to calculate elasticities.

5. Cervero, R. (1993) "Evidence on Travel Behavior in Transit-Supportive Residential Neighborhoods," *Transit-Supportive Development in the United States: Experiences and Prospects*, Technology Sharing Program, U.S. Department of Transportation, Washington, D.C., pp. 127-163.

   Based on U.S. Census Journey-to-Work data and hence limited to one-quarter of all trips, limited number of neighborhoods in database, and travel statistics aggregated.

6. Cervero, R. (1994a). "Transit-based Housing in California: Evidence on Ridership Impacts," *Transportation Policy*, Vol. 1, No. 3, pp. 174-183.

   Only two 3D variables (residential and destination densities) tested, and only rail transit variables explained.

7. Douglas, G.B. and J.E. Evans (1997) "Urban Design, Urban Form, and Employee Travel Behavior," paper presented at the Sixth Conference on the Application of Transportation Planning Methods, Transportation Research Board, Washington, D.C.

   Only four activity centers included in database, limited 3D information for the four centers, and no socioeconomic controls.

8. Ewing, R. (1996) *Pedestrian- and Transit-Friendly Design*, Florida Department of Transportation, Tallahassee, Appendix C.

   While a rich array of 3D variables is available for transit service areas, the only travel variable explained is the number of bus boardings.

9. Friedman, B., S.P. Gordon, and J.B. Peers (1994) "Effect of Neotraditional Neighborhood Design on Travel Characteristics," *Transportation Research Record 1466*, pp. 63-70.

   Inadequate socioeconomic controls, and no 3D information available for the neighborhoods compared.

10. Kitamura, R., P. Mokhtarian, and L. Laidet (1995) "A Micro-Analysis of Land Use and Travel in Five Neighborhoods in the San Francisco Bay Area," paper presented at the 74th Annual Meeting, Transportation Research Board, Washington, D.C.

    Lack of data needed to calculate elasticities.

11. Kockelman, K.M. (1995) "Which Matters More in Mode Choice: Density or Income?" *ITE 1995 Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., pp. 844-867.

    Based on U.S. Census Journey-to-Work data and hence limited to one-quarter of all trips, only one 3D variable (density) tested, and travel statistics aggregated.

12. Loutzenheiser, D.R. (1997) "Pedestrian Access to Transit: A Model of Walk Trips and Design and Urban Form Determinants Around BART Stations," paper presented at the 76th Annual Meeting, Transportation Research Board, Washington, D.C.

Lack of data needed to calculate elasticities.

13. Messenger, T. and R. Ewing (1996) "Transit-Oriented Development in the Sunbelt," *Transportation Research Record 1552*, pp. 145-152.

Based on U.S. Census Journey-to-Work data and hence limited to one-quarter of all trips, and only transit mode share explained.

14. Miller, E.J. and A. Ibrahim (1998) "Urban Form and Vehicular Travel: Some Empirical Findings," paper presented at the 77th Annual Meeting, Transportation Research Board, Washington, D.C.

Based on Toronto data that may not be generalizable to the U.S., only work-related VMT is analyzed, and a limited set of 3D variables tested.

15. Parsons Brinckerhoff Quade & Douglas (1996) *Transit and Urban Form, Volume 1*, Transit Cooperative Research Program Report 16, Transportation Research Board, Washington, D.C.

Subsequent work shows the effect of density estimated here is significantly overstated.

16. Replogle, M. (1990) "Computer Transportation Models for Land Use Regulation and Master Planning in Montgomery County, Maryland," *Transportation Research Record 1262*, pp. 91-100.

A travel modeling exercise where land use-travel relationships are not fully explored.

17. Ross, C.L. and A.E. Dunning (1997) "Land Use Transportation Interaction: An Examination of the 1995 NPTS Data," prepared for the Federal Highway Administration, Washington, D.C.

Based on NPTS and hence broadly cross-sectional, and limited to one 3D variable (density).

18. San Diego Association of Governments (1993) "Trip Making in Traditional San Diego Communities," Unpublished working paper, 1993.

Weak socioeconomic controls, small sample size, and no comparative data on the two types of communities.

19. Sasaki Associates, Inc. (1993) *Transit and Pedestrian Oriented Neighborhoods*, Maryland-National Capital Park & Planning Commission, Silver Spring, MD, pp. 47-53.

Based on U.S. Census Journey-to-Work data and hence limited to one-quarter of all trips, limited number of neighborhoods in database, and travel statistics aggregated.

20. Spillar, R.J. and G.S. Rutherford (1990) "The Effects of Population Density and Income on Per Capita Transit Ridership in Western American Cities," *ITE 1990 Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, D.C., pp. 327-331.

Based on U.S. Census Journey-to-Work data and hence limited to one quarter of all trips, limited number of neighborhoods in database, and travel statistics aggregated.

Appendix C
AIR POLLUTANT & GREENHOUSE GAS EMISSION FACTORS

SGI estimates air pollutant and greenhouse gas emissions for residential buidings and household travel as part of the indicator results for each sketch.

Table C-1 lists the emission coefficients used for electricity and natural gas consumption in the buildings sector. These coefficients are based on data published by the U.S. Department of Energy's Lawrence Berkeley Laboratory for natural gas utilization, and the Energy Information Administration for electricity utilization (including regional variations in electric generation resource mix).

Table C-2 presents emission coefficients used for autos and light trucks in the transportation sector based on data published by U.S. EPA's Office of Mobile Sources. SGI presently assumes a 50/50 mix of autos and light trucks when estimating transportation emissions.

It should be noted that estimates for both the buildings and transportation sectors are based on current emission rates, and do not take into consideration potential changes in future emission rates when long-range forecast sketches are prepared.

Table C-1
RESIDENTIAL BUILDING EMISSION FACTORS

	LBS/MMBTU					
	NOx	**SOx**	**HC**	**CO**	**CO2**	**PM**
Electricity	0.413	0.6514	0.003	0.0206	125.65	0.0653
Natural Gas	0.137	0.00059	0.00058	0.034	115	0.006

Source: U.S. DOE, LBL and EIA, 1997.

Table C-2
VEHICLE EMISSION FACTORS

A. Annual Emissions and Fuel Consumption for an "Average" Passenger Car [1]

Pollutant Problem	Amount [2]	Miles [3]	Pollution or Fuel Consumption [4]
Hydrocarbons	2.9 grams/mile	12,500	80 lbs of HC
Carbon Monoxide	22 grams/mile	12,500	606 lbs of CO
Nitrogen Oxides	1.5 grams/mile	12,500	41 lbs of NOx
Carbon Dioxide	0.8 pound/mile	12,500	10,000 lbs of CO2

B. Annual Emissions and Fuel Consumption for an "Average" Light Truck [1]

Pollutant Problem	Amount [2]	Miles [3]	Pollution or Fuel Consumption [4]
Hydrocarbons	3.7 gram/mile	14,000	114 lbs of HC
Carbon Monoxide	29 gram/mile	14,000	894 lbs of CO
Nitrogen Oxides	1.9 gram/mile	14,000	59 lbs of NOx
Carbon Dioxide	1.2 pound/mile	14,000	16,800 lbs of CO2

Notes:

[1] These values are averages. Individual vehicles may travel more or less miles and may emit more or less pollution per mile than indicated here. Emission factors and pollution/fuel consumption totals may differ slightly from original sources due to rounding.

[2] The emission factors used here come from standard EPA emission models. They assume an "average," properly maintained car or truck on the road in 1997, operating on typical gasoline on a summer day (72 to 96 degrees F). Emissions may be higher in very hot or very cold weather.

[3] Average annual mileage source: EPA emissions model MOBILE5.

[4] Fuel consumption is based on average in-use passenger car fuel economy of 22.5 miles per gallon and average in-use light truck fuel economy of 15.3 miles per gallon.

Source: U.S. Environmental Protection Agency
National Vehicle and Fuel Emissions Laboratory, April 1997

Appendix D

APPLICATION GUIDELINES & INDICATOR DICTIONARY

CONTENTS

1. Introduction

This appendix describes ways in which the Smart Growth INDEX (SGI) software can support community planning processes. The guide devotes particular attention to SGI's indicators, including detailed definitions and guidance on their application.

SGI is a GIS-based sketch tool intended to help stakeholders and decision-makers:

- ***Create plans*** through issues identification, alternatives analysis, and goal-setting.
- ***Implement plans*** by evaluating development consistency with goals.
- ***Achieve plans*** by measuring cumulative progress toward goals.

At its heart is a set of indicators that are used to benchmark existing conditions, evaluate alternative courses of action, and monitor change over time. Indicators are measurements of key community characteristics that provide insights into overall conditions. For example, the residential density indicator of "dwellings per acre" is a useful measurement of an area's suitability for transit service because of its spatial representation of potential ridership.

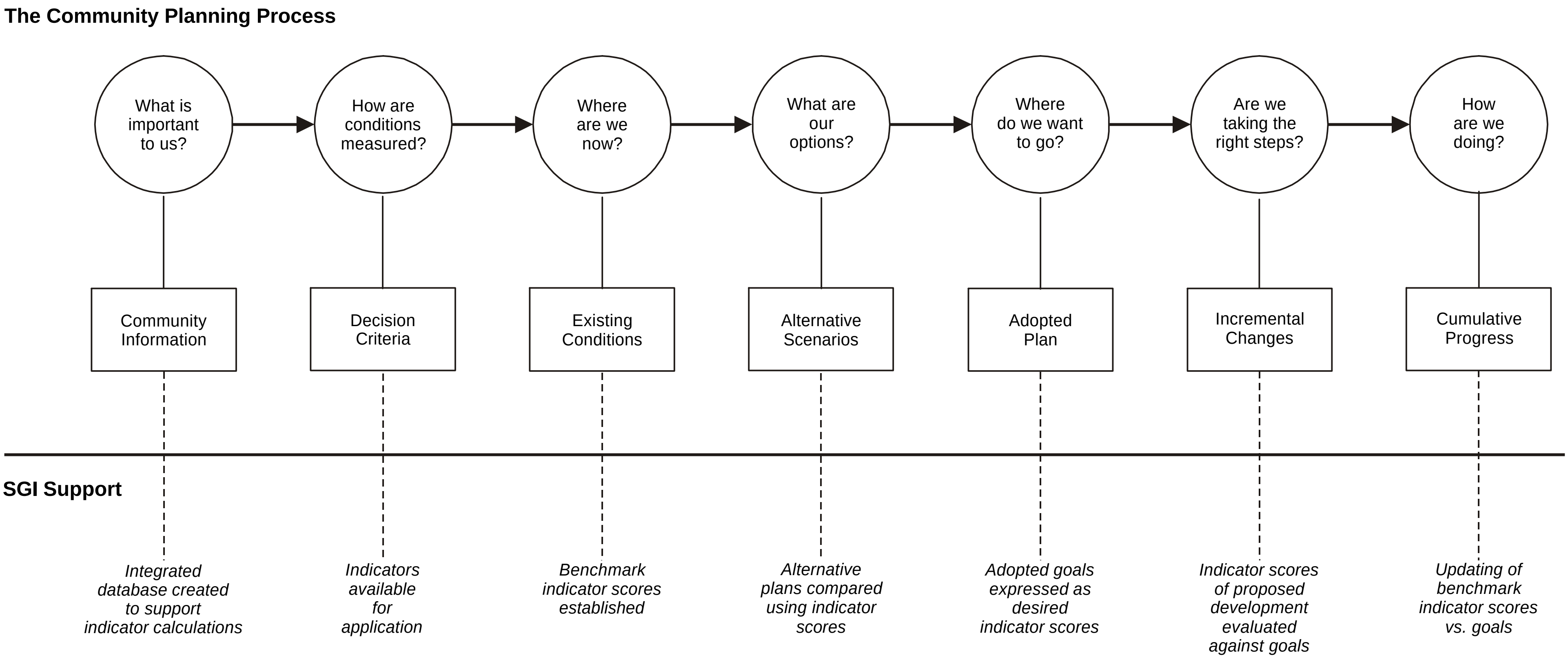
The premise of SGI is that community plan formulation and implementation can be valuably informed by a standardized set of indicator measurements that are used regularly to gauge planning actions. Figure D-1 illustrates a typical community planning process and the stages where the tool can provide decision-making support. Some communities may choose to apply the tool systematically in all stages, while some may find it most helpful at one or two points.

Important process-related features of the software include:

- *Sketches.* Any number of planning scenarios or "sketches" can be modeled in an area. Sketches can represent actual or proposed conditions. Usually a "base" sketch is used as a starting point in an application and "alternative" sketches are created to represent different ideas and approaches to the issues at hand.

- *Sketch areas.* The software can be applied to any portion of a region or community where data is available to support indicator calculations. Sketch areas may be created using official boundaries, such as local government jurisdictions, traffic analysis zones, zip codes, or other administrative boundaries. Natural features such as watersheds may be used, or users may also create unique one-of-a-kind boundaries to fit special needs.

Figure D-1. SUPPORT OF COMMUNITY PLANNING WITH SGI



- *Type of sketch.* SGI can create two types of sketches, either a forward-looking "forecast" or a single point-in-time "snapshot." Forecast sketches are usually created when stakeholders are preparing long-range growth plans for entire communities or regions, or large parts of them. Snapshot sketches are usually prepared for purposes of impact assessment, either under today's conditions or at an assumed future date. Forecast sketches are known as dynamic analyses because they simulate change over time, and snapshot sketches are known as static analyses because of their single point-in-time calculations. Forecast sketches use a "rasterized" grid of cells to represent geography, while snapshot sketches use actual property parcels.

- *Indicators.* Indicators are "yardsticks" for identifying an area's strengths and weaknesses, testing alternative courses of action, and monitoring change over time. SGI has a menu of 28 indicators available for evaluating sketches. From this menu, users may select those indicators that are most relevant to a given situation from categories of land-use, housing, employment, travel, and environment. To make the most effective use of SGI, users need to be familiar with the measurements made by the indicators in order to determine which indicators are relevant to a particular study or project; and to correctly interpret indicator scores, including the desired direction of change in scores (increase or decrease) when evaluating alternative scenarios. Figure D-2 illustrates the two kinds of indicator measurements made by SGI: first, a numerical score for the sketch area; and second, mapping of the spatial pattern that produced the score. In this way users obtain both quantitative and geographic assessments of an area. The numeric scores are interpreted in relation to typical standards in the professional literature, common conditions in the local area, other alternative sketch scores, or adopted goals in cases where they already exist. The geographic results are used to delineate areas where strengths can be protected and areas where weaknesses need to be corrected.

2. Organizing Applications

Once SGI is installed, there are three basic process-related tasks in organizing sketches:

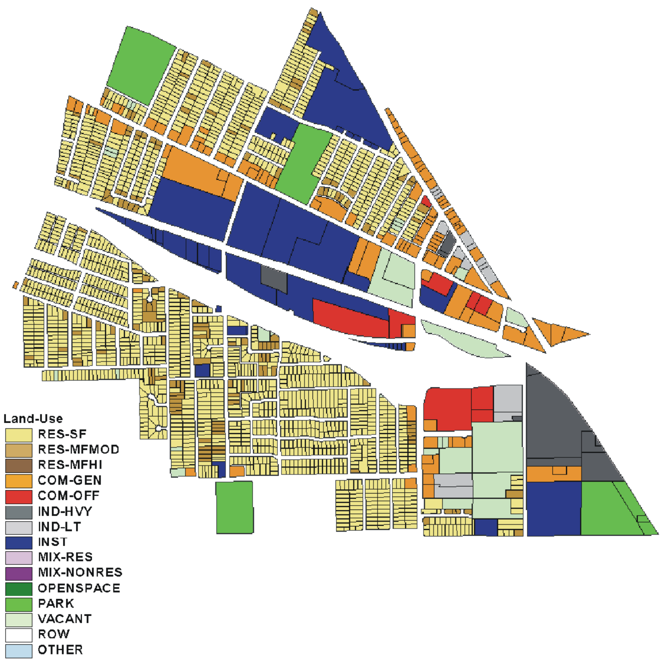
- *Select a sketch boundary.* The boundary should be derived from the scope and objective of the sketch, e.g. city limits if an entire municipality is being evaluated, or the neighborhood vicinity if a major development proposal is being examined. In all cases, care should be exercised along the boundary edge to insure that important adjacent features that affect the sketch area are included, e.g. an elementary school near the boundary of a residential area study.

Figure D-2. INDICATOR EXAMPLE: HOUSING PROXIMITY TO PARKS

Indicator Score

2,049 ft.
Average walk distance from all dwellings to closest park.

Sketch Area



Indicator Mapping

- *Select a sketch type.* The question of whether to prepare a forecast or snapshot sketch usually goes hand-in-hand with boundary selection because the two items are closely linked. Forecast sketches simulate spatial growth for up to 20 years into the future, and their boundaries usually encompass entire communities or regions, or large portions of them. Snapshot sketches can also be prepared for large areas, but because of their parcel-based detail they are also suitable for small, neighborhood-scale sketches.

- *Select indicators.* To evaluate sketches, users select those indicators that are most relevant to the issues at hand, e.g. employment-related indicators for an office park versus housing indicators for a residential subdivision. Occasionally, a user may select all indicators when a comprehensive set of measurements is desired, such as benchmarking existing conditions at the outset of a community planning process. At the time indicators are selected, users will also want to agree on the desired direction of change in each indicator's score from sketch to sketch, e.g. a neighborhood infill project might want to see housing and employment density scores increase, and distance to transit and other amenities decrease. Making these determinations at the outset of a process will help stakeholders interpret indicator scores as the process unfolds.

To illustrate a simplified SGI application, a series of hypothetical neighborhood snapshot sketches are shown in Figure D-3. This example assumes a policy initiative to densify employment along an arterial corridor to encourage travel mode shifting to transit. The objective is to create a corridor of ridership that will support frequent transit service. "Employees per acre" is selected as a key indicator of transit service feasibility (higher employment density supports greater frequency in transit service). Each panel in Figure D-3 is discussed sequentially in the following sections as the neighborhood planning process unfolds.

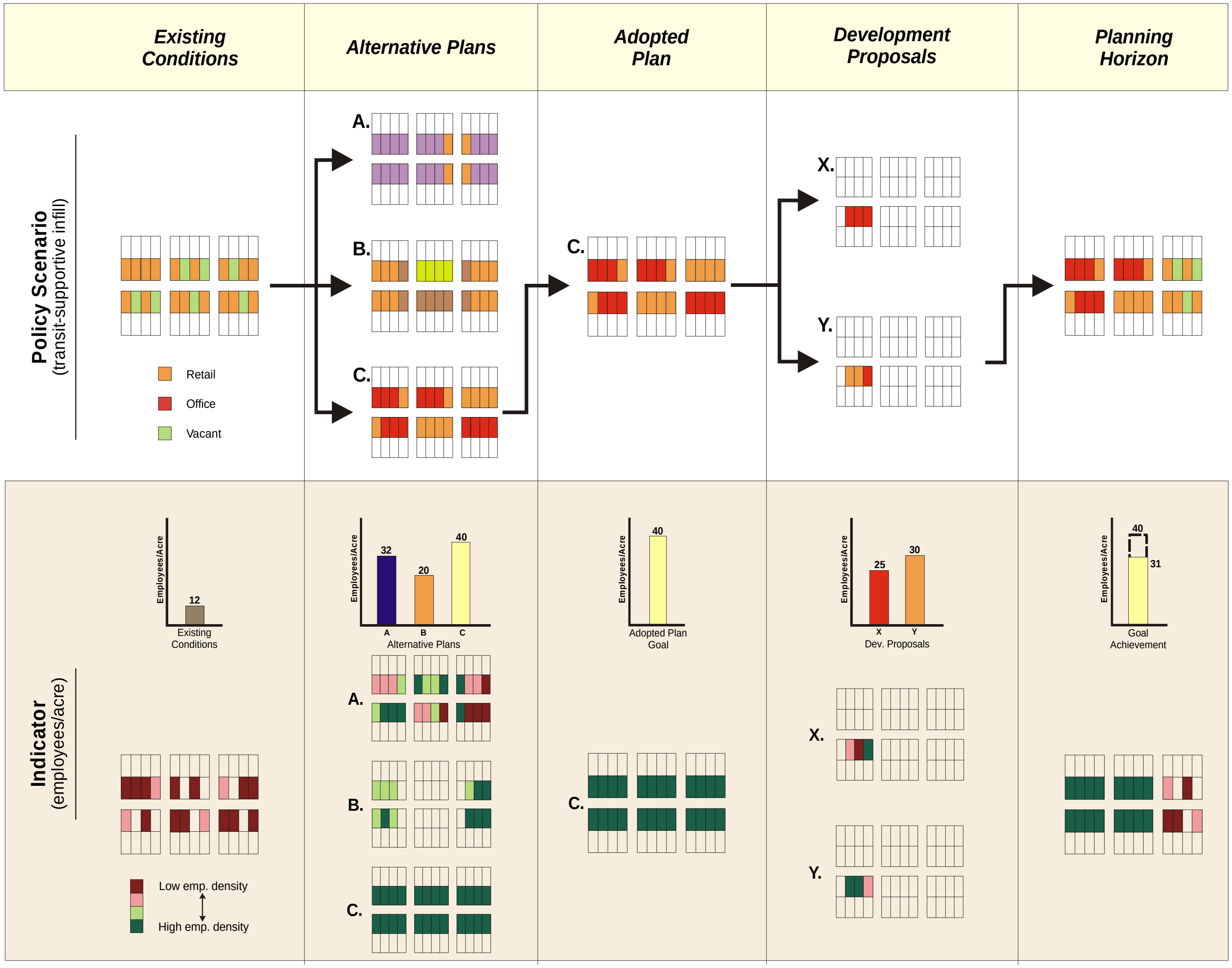
3. Benchmarking Current Conditions

Most SGI applications will begin with benchmark measurements of existing conditions in a sketch area. Existing condition indicator scores can be calculated in either forecast or snapshot sketches, and are used to:

- *Identify an area's strengths and weaknesses.* Benchmark scores and mapping will reveal problems and opportunities that merit attention in plans.

- *Provide input into the formulation of community standards.* Benchmark scores are an important reference point when formulating policy standards that will be applied to community development.

Figure D-3. HYPOTHETICAL APPLICATION OF SMART GROWTH INDEX



- *Provide a baseline for gauging change.* During plan implementation when development proposals are evaluated, the proposals' scores can be compared to benchmark measurements to gauge the amount of change that development would cause.

- *Provide a baseline for gauging progress.* During periodic monitoring of plan accomplishments, updated benchmark measurements can be compared against previous benchmarks to gauge cumulative progress toward goals.

Benchmarking is shown in the left-hand panel of Figure D-3, where the indicator finds a relatively low 12 employees/acre, which is insufficient to support frequent transit service. This segment of the neighborhood corridor therefore meets the threshold issue test of needing land-use changes to increase employment density.

4. Creating Plans

Once existing conditions have been assessed and action issues identified, stakeholders can use forecast or snapshot sketches to create and evaluate alternative plans that respond to the issues. These can range from comprehensive community plans to any number of special-purpose regional or neighborhood plans. Alternatives can be evaluated as forecast or snapshot sketches according to the following general sequence.

- *Preparation of alternative plans.* In response to identified issues stakeholders can create any number of alternative plans. Each of these is represented by a sketch in the software, with each sketch containing its own unique mix of features. For example, if housing was identified as an issue, one alternative might contain a mix of single and multi-family dwellings while another alternative might have only single-family units.

- *Review of alternative scores.* Stakeholders review alternative sketch indicator scores and mapping in comparison to other alternatives and benchmarks to determine which alternatives respond most effectively to identified issues. For example, if excessive walking distance to parks was identified as a problem at the outset, stakeholders would review the alternatives' park proximity scores to determine which alternative offered the shortest walking distance.

- *Iteration to preferred alternative and adopted plan.* Using the software to provide rapid adjustment of sketches and feedback of results, stakeholders can iterate among alternatives to a preferred, and ultimately adopted, plan.

- *Modeling of adopted goals.* Once a plan is formally adopted, its build-out or full implementation can be modeled and the resulting indicator scores used as quantitative expressions of its goals.

In the Figure D-3 example, three alternative plans are suggested for the neighborhood corridor by stakeholders: a) vertical mixed-use with employment on lower floors and housing on upper floors; b) new commercial retail with separate multi-family housing and a small park; and c) a mix of offices and retail. The three alternative plans are scored with the employment density indicator producing results of 32, 20, and 40 employees/acre, respectively. Given the hypothetical policy objective of increased density for transit support, Plan C is adopted and its build-out measurement of 40 employees/acre becomes the corridor's goal.

5. Implementing Plans

Once plans are adopted, SGI can help implement them by evaluating the consistency of development proposals against plan goals. It can also gauge the magnitude of change that a development would cause. These implementation checks can be accomplished with snapshot sketches according to the following general sequence:

- *Acquire development proposal in GIS form.* In order to apply SGI as a development evaluation tool, it will be necessary to obtain development proposals in GIS form. Given the widespread use of CAD in preparing development plans and the relatively easy conversion of CAD files to GIS format, many communities are finding it reasonable to request major development proposals in GIS format.

- *Score base case development proposal.* The development proposal is scored with relevant indicators and the results are: 1) compared to existing conditions to gauge the amount of change the development would cause; and 2) compared to adopted goals to determine how much goal achievement the development would accomplish.

- *Iterate to acceptable proposal.* Again using the software's capability for rapid sketch modification and feedback, stakeholders and decision-markers can iterate to an acceptable development scheme during the permitting process.

In the Figure D-3 example, this step shows two versions of a development proposal, X and Y. Proposal X contains offices and Proposal Y includes offices plus retail. The employment density indicator reveals that Proposal Y's employment density is 20% greater than Proposal X, and is therefore preferred because it is more supportive of the adopted corridor goal.

6. Achieving Plans

Periodically, snapshot sketches can be used to measure cumulative change and overall progress toward goals. This type of application would include the following steps:

- *Retrieve benchmark indicator scores.* Indicator scores from the previous benchmark year are used as the starting point, e.g. year 2000.

- *Incorporate built and natural environment changes.* The model's database is updated with constructed changes in the built environment, and resulting changes in the natural environment, that have occurred during the reporting period, e.g. 2000-2005.

- *Update indicator scores.* An updated "existing conditions" case is scored to establish new measurements for the new benchmark year, e.g. 2005. The changes in indicator scores between 2000 and 2005 become the amount of goal achievement for the period.

In the Figure D-3 example, cumulative changes over several years are measured, revealing a density increase from 12 to 31 employees/acre, which is substantial partial achievement of the goal of 40 employees/acre. However, despite this areawide progress, indicator mapping shows a continuing weakness in employment density in the eastern portion of the corridor where additional attention needs to be focused in order to fully achieve the plan.

7. Special Purpose Applications

In addition to the generic planning process described above, SGI can be applied to any special purpose study where SGI's indicators are relevant to the study's scope or objectives. Examples include municipal annexations, environmental impact reports, capital improvement planning, and facility siting. Any kind of comparative evaluation or trade-off analysis that is land-based could conceivably be simulated in SGI providing that its indicators are relevant to the issues at hand.

8. Examples of Community Indicator Results

To further illustrate the use of indicators, this section of the guide presents a hypothetical community that has applied SGI in two planning situations. The first application is a forecast sketch of the community's land-use plan and the second is a snapshot sketch of a redevelopment site in the center of the community.

Figure D-4 presents two alternative land-use plans that have been evaluated with forecast sketches. In this example, the community's urban growth boundary was used as the sketch boundary and the year 2020 was used as the planning horizon. The "business as usual" alternative shown on the left of Figure D-4 represents continued agricultural land conversion to low-density residential use, and continued strip development along arterial corridors. In contrast on the right, the "smart growth" alternative retains much of the agricultural land and instead allocates residential growth to a more diverse mix of housing types centrally located in the community. Employment and shopping are similarly concentrated where infill opportunities and existing infrastructure can accommodate them, and where multi-modal travel is more feasible.

Indicator results for the two alternative plans are shown in Table D-1 in comparison to existing conditions. The "business as usual" plan would result in lower residential and employment densities, and these conditions, in turn, would produce greater auto dependency, higher travel costs, increased energy and water use, and more pollutant emissions than current conditions. In contrast, the "smart growth" plan results in higher densities, creating a built environment that is more transit-oriented and less auto-dependent, with lower energy and water consumption rates, and reduced pollutant emissions. The "smart growth" alternative is therefore considered preferable because of its superior sustainability.

Turning to the snapshot example, Figure D-5 shows a 30-acre redevelopment site in the center of the community. Having adopted the "smart growth" plan described above, community stakeholders formulated two alternative redevelopment plans for the site as also shown in Figure D-5. The first alternative responds to infill housing goals with a proposed multi-family residential project in the lower left; and the second alternative responds to open space goals with a multi-use park proposal in the lower right. These snapshot sketches used a one-half mile radius boundary surrounding the subject property to evaluate the impacted neighborhood with and without each proposal.

Indicator results for the redevelopment alternatives are shown in Table D-2 in comparison to existing conditions. Adding the multi-family residential project to the neighborhood would improve the area's conformance with the community plan in several respects: higher residential density, increased use mix, better jobs/housing balance, greater multi-modal travel, less energy and water use, and less pollutant emissions. Alternatively, the park plan's benefits are limited to greater park space and closer park proximity for area residents. Although these latter benefits are worthy, on balance the residential alternative appears to be more consistent with community goals for the area.

It should be kept in mind that these are highly simplified examples, and SGI indicator scores do not necessarily constitute the "best answer" to every situation. Stakeholders in real world conditions will want to use a variety of tools; SGI should only be one of several sources of information used to build consensus in community planning processes.

Figure D-4. ALTERNATIVE COMMUNITY LAND-USE PLANS

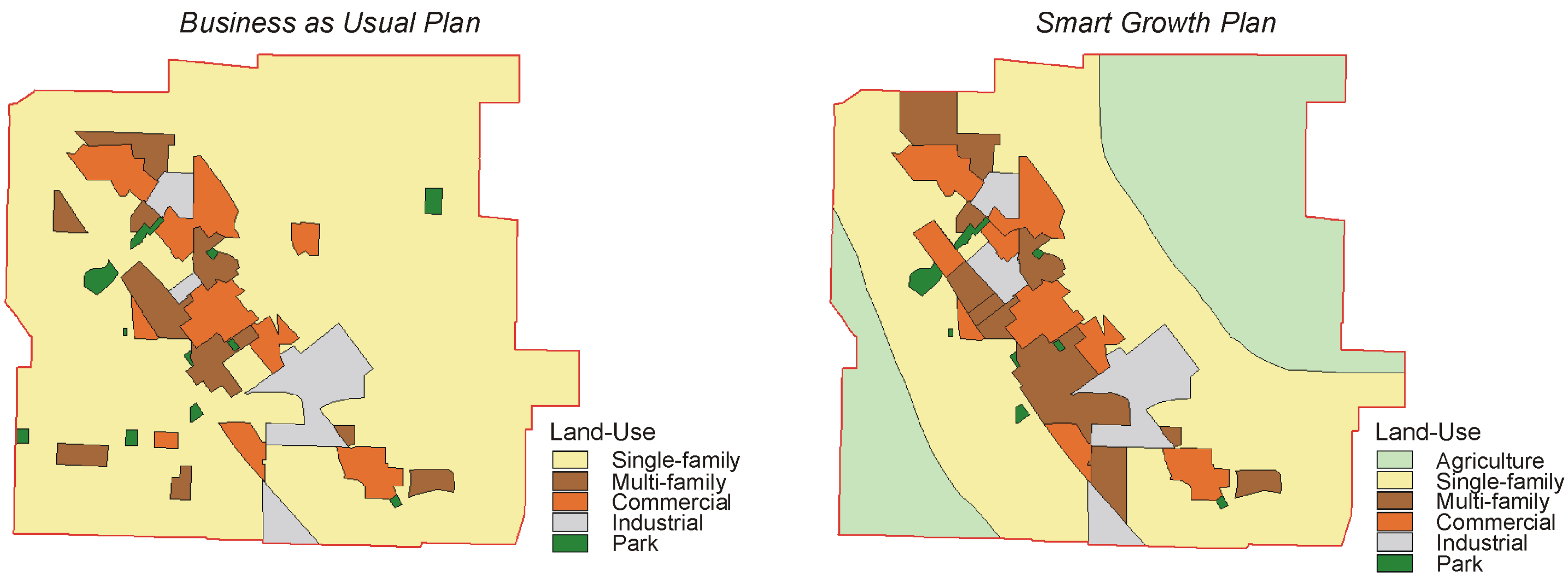


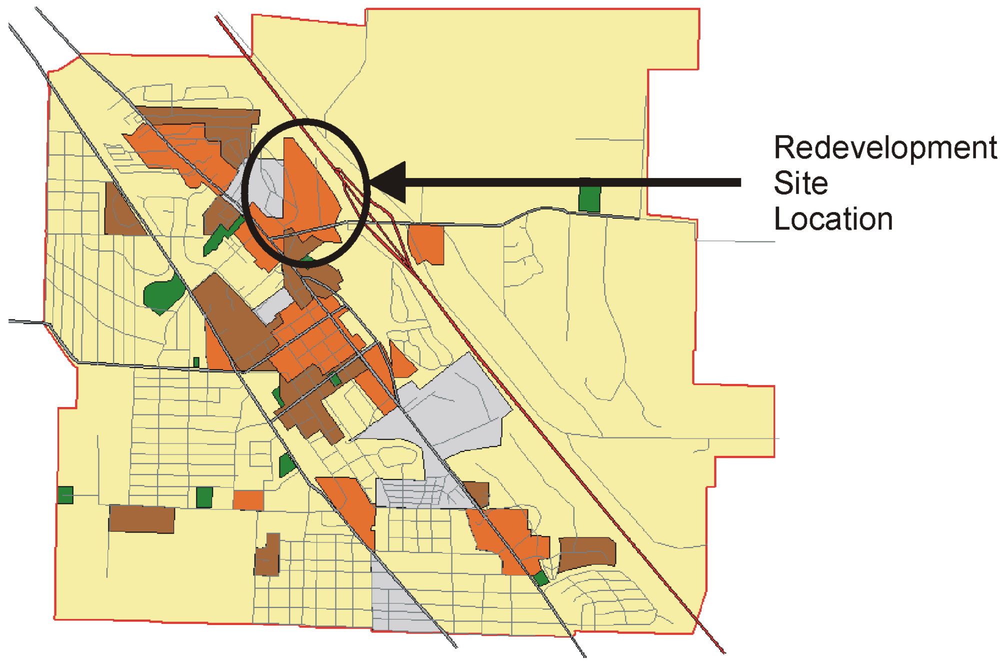
Table D-1
COMPARISON OF FORECAST INDICATOR SCORES

	Selected Indicators	Forecast Sketches: Existing Conditions	Forecast Sketches: Business as Usual Plan	Forecast Sketches: Smart Growth Plan	Indicator Units
Land-Use					
Growth compactness	✔	8,500	8,400	11,000	Persons/sq.mi. in developable area
Population density	✔	8,200	8,100	10,600	Persons/sq.mi. in total area
Incentive area use for housing					
Incentive area use for employment					
Jobs/workers balance					
Housing					
Housing density	✔	5	4	9	Dwelling units/acre
Housing transit proximity	✔	8	6	23	% dwellings w/i 1/4 mi. of route
Residential energy use	✔	125	135	110	MMBtu/yr./capita
Residential water use	✔	150	150	125	Gal./day/capita
Employment					
Employment density	✔	10	8	17	Employees/acre
Employment transit proximity	✔	14	12	31	% employees w/i 1/4 mi. of route
Travel					
Vehicle miles traveled	✔	20	22	17	Total VMT/day/capita
Vehicle trips	✔	5	6	4	Total VT/day/capita
Arterial vehicle hours traveled	✔	0.20	0.25	0.15	VHT/day/capita
Freeway vehicle hours traveled	✔	0.10	0.14	0.10	VHT/day/capita
Arterial vehicle hours of delay	✔	0.09	0.11	0.06	VHD/day/capita

Table D-1 *Continued*

	Selected Indicators	Forecast Sketches			Indicator Units
		Existing Conditions	Business as Usual Plan	Smart Growth Plan	
Travel Continued					
Freeway vehicle hours of delay	✔	0.06	0.08	0.04	VHD/day/capita
Auto driver mode share	✔	87	88	79	% daily person trips
Auto passenger mode share	✔	5	5	6	% daily person trips
Transit mode share	✔	5	6	9	% daily person trips
Walk/bike mode share	✔	3	3	6	% daily person trips
Auto travel costs	✔	7,600	8,000	6,100	$/household/yr.
Environment					
Oxides of nitrogen (NOX) emissions	✔	21	23	18	Lbs./yr./capita
Oxides of sulfur (SOX) emissions	✔	275	280	255	Lbs./yr./capita
Hydrocarbon (HC) emissions	✔	270	275	250	Lbs./yr./capita
Carbon monoxide (CO) emissions	✔	246	259	231	Lbs./yr./capita
Particulate matter (PM) emissions	✔	256	264	249	Lbs./yr./capita
Greenhouse gas emissions	✔	8,600	8,900	8,000	Lbs./yr./capita

Figure D-5. REDEVELOPMENT SITE & ALTERNATIVE PLANS



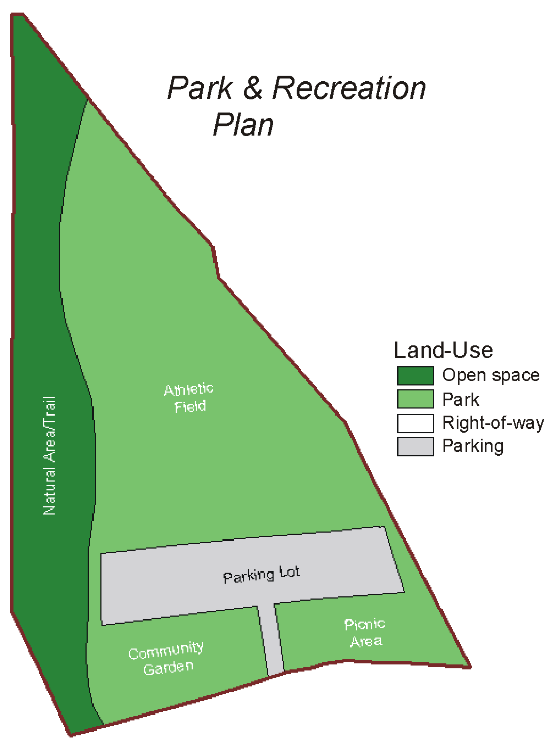


Table D-2
COMPARISON OF SNAPSHOT INDICATOR SCORES

	Selected Indicators	Snapshot Sketches			Indicator Units
		Existing Conditions	Residential Alternative	Park & Rec. Alternative	
Land-Use					
Population density	✔	7,000	7,200	7,000	Person/sq.mi.
Use mix	✔	0.40	0.55	0.50	0 to 1 scale (1 = high)
Jobs/workers balance	✔	0.8	0.9	0.8	Jobs/total employed residents ratio
Housing					
Residential density	✔	9	13	9	Dwelling unit/acre
Single-family housing share					
Multi-family housing share	✔	22	31	22	% of total dwellings
Housing transit proximity	✔	45	53	45	% dwellings w/i 1/4 mi. of stops
Housing recreation proximity	✔	30	24	56	% of dwellings w/i 1/4 mi. of parks
Residential energy use	✔	125	121	125	MMBtu/yr./capita
Residential water use	✔	150	136	150	Gal./day/capita
Employment					
Employment density					
Employment transit proximity					
Travel					
Sidewalk completeness					
Pedestrian route directness					
Pedestrian design index					
Street network density					
Street connectivity					

Table D-2 *Continued*

	Selected Indicators	Snapshot Sketches			Indicator Units
		Existing Conditions	Residential Alternative	Park & Rec. Alternative	
Travel Continued					
Vehicle miles traveled	✔	20	19	20	Total VMT/day/capita
Vehicle trips	✔	5	4.5	5	Total VT/day/capita
Auto travel costs	✔				$/household/yr.
Environment					
Open space	✔	4	4	11	% total area
Park space availability	✔	1.5	1.6	3.0	Acres/1,000 residents
Carbon monoxide (CO) emissions	✔	246	241	246	Lbs./yr./capita
Hydrocarbon (HC) emissions	✔	270	266	270	Lbs./yr./capita
Oxides of sulfur (SOX) emissions	✔	275	270	275	Lbs./yr./capita
Oxides of nitrogen (NOX) emissions	✔	21	19	21	Lbs./yr./capita
Particulate matter (PM) emissions	✔	256	252	256	Lbs./yr./capita
Carbon dioxide (CO_2)	✔	8,600	8,550	8,600	Lbs./yr./capita

INDICATOR DICTIONARY

Forecast Indicators

Land-Use

Indicator Name:	**Growth compactness.**
Definition and Units:	Persons/sq.mi. in developable portion of sketch area including residents and employees. The “developable” portion of the sketch area includes all land-use classes that allow construction and that are not constraint-designated by the user.
Illustrative Scores:	Varies widely by type of community and sketch area characteristics, e.g. 3,000-100,000 persons per sq.mi.

Indicator Name:	**Population density.**
Definition and Units:	Persons per sq.mi. in total sketch area, including residents and employees.
Illustrative Scores:	Varies widely by type of community and sketch area characteristics, e.g. 3,000-100,000 persons per sq.mi.

Indicator Name:	**Incentive area use for housing.**
Definition and Units:	Percent of total housing capacity utilized in user-designated incentive areas.
Illustrative Scores:	Will vary widely, e.g. 25-75%, based on locational attributes of incentive area.

Indicator Name:	**Incentive area use for employment.**
Definition and Units:	Percent of total employment capacity utilized in user-designated incentive areas.
Illustrative Scores:	Will vary widely, e.g. 25-75%, based on locational attributes of incentive area.

Indicator Name:	**Jobs/workers balance.**
Definition and Units:	Ratio of total jobs to total employed residents (assuming a constant 1.4 workers per household).
Illustrative Scores:	0.2 would represent a predominantly residential area; 1.0 would represent a perfect balance of jobs and workers; 2.0 would represent a predominantly non-residential area.

Housing

Indicator Name:	**Housing density.**
Definition and Units:	Average dwelling units per net acre of all land designated for residential uses. Net density excludes public rights-of-way and similar non-buildable land.
Illustrative Scores:	4 to 5 DU/acre for low-density areas; 50 to 60 DUs/acre for high-density areas.

Indicator Name:	**Housing transit proximity.**
Definition and Units:	Percent of dwellings within 1/4 mi. of transit route.
Illustrative Scores:	Varies widely based on extent of transit service, e.g. 10-30%.

Indicator Name:	**Residential energy use.**
Definition and Units:	Energy consumed for housing and auto travel in million Btu per capita per year.
Illustrative Scores:	75-200. Scores will vary depending on combinations of climate and travel mode shares.

Indicator Name:	**Residential water use.**
Definition and Units:	Water consumed for all residential purposes (interior and exterior) in gallons per day per capita.
Illustrative Scores:	100 to 150 gal/day/capita.

Employment

Indicator Name:	**Employment density.**
Definition and Units:	Number of employees per net acre of land designated for employment uses. Net density excludes public rights-of-way and similar non-buildable land.
Illustrative Scores:	5 to 10 employees/acre for low-density employment areas; 50 to 60 employees/acre for high-density employment areas.

Indicator Name:	**Employment transit proximity.**
Definition and Units:	Percent of employees within 1/4 mi. of transit route.
Illustrative Scores:	Varies widely based on extent of transit service, e.g. 20-40%.

Travel

Indicator Name:	**Vehicle miles traveled.**
Definition and Units:	Average total vehicle miles traveled daily per capita.
Illustrative Scores:	15 VMT/day/capita in dense multi-modal areas; 25 VMT/day/capita in low-density auto-dependent areas.

Indicator Name:	**Vehicle trips.**
Definition and Units:	Average daily total vehicle trips per capita.
Illustrative Scores:	4-5 vehicle trips/day/capita.

Indicator Name:	**Arterial vehicle hours traveled.**
Definition and Units:	Arterial vehicle hours traveled/day/capita.
Illustrative Scores:	0.10-0.30 VHT/day/capita.

Indicator Name:	**Freeway vehicle hours traveled.**
Definition and Units:	Freeway vehicle hours traveled/day/capita.
Illustrative Scores:	0.10-0.20 VHT/day/capita.

Indicator Name:	**Arterial vehicle hours of delay.**
Definition and Units:	Arterial vehicle hours delay/day/capita.
Illustrative Scores:	0.010-0.020 VHT/day/capita.

Indicator Name: **Freeway vehicle hours of delay.**

Definition and Units: Freeway vehicle hours delay/day/capita.

Illustrative Scores: 0.005-0.015 VHD/day/capita.

Indicator Name: **Auto driver mode share.**

Definition and Units: Percent of daily person trips as auto driver.

Illustrative Scores: 80-95%.

Indicator Name: **Auto passenger mode share.**

Definition and Units: Percent of daily person trips as auto passenger.

Illustrative Scores: 5-20%.

Indicator Name: **Transit mode share.**

Definition and Units: Percent of daily person trips by transit.

Illustrative Scores: 3-15%.

Indicator Name: **Walk/bike mode share.**

Definition and Units: Percent of daily person trips by walk or bike.

Illustrative Scores: 3-10%.

Indicator Name: **Auto travel costs.**

Definition and Units: Annual average household cost for auto travel in $/year based on American Automobile Association cost per mile data and VMT estimate.

Illustrative Scores: $5,000 - 10,000 year.

Environment

Indicator Name: **Oxides of nitrogen (NOX) emissions.**

Definition and Units: NOX emitted from light vehicles in lbs/capita/year.

Illustrative Scores: 15-25 lbs./year/capita.

Indicator Name: **Oxides of sulfur (SOX) emissions.**

Definition and Units: SOX emitted from light vehicles in lbs/capita/yr.

Illustrative Scores: 10-15 lbs/yr/capita.

Indicator Name: **Hydrocarbon (HC) emissions.**

Definition and Units: HC emitted from light vehicles in lbs/capita/yr.

Illustrative Scores: 15-25 lbs/yr/capita.

Indicator Name: **Carbon monoxide (CO) emissions.**

Definition and Units: CO emitted from light vehicles in lbs/capita/year.

Illustrative Scores: 200-300 lbs./year/capita.

Indicator Name: **Particulate matter (PM) emissions.**

Definition and Units: PM emitted from light vehicles in lbs/capita/yr.

Illustrative Scores: 1-10 lbs/yr/capita.

Indicator Name: **Greenhouse gas emissions.**

Definition and Units: Carbon dioxide (CO2) emitted from light vehicles in lbs/capita/year.

Illustrative Scores: 7,000-10,000 lbs./year/capita.

Snapshot Indicators

Land-Use

Indicator Name:	**Population density.**
Definition and Units:	Persons per sq.mi. in total sketch area, including residents and employees.
Illustrative Scores:	Varies widely by type of community and sketch area characteristics, e.g. 3,000-100,000 persons per sq.mi.

Indicator Name:	**Use mix.**
Definition and Units:	Proportion of dissimilar land-uses among a grid of one-acre cells, expressed on a scale of 0 to 1 (1 is high).
Illustrative Scores:	0.3 to 0.4 for moderately diverse areas; 0.6 to 0.7 for highly diverse areas.

Indicator Name:	**Jobs/workers balance.**
Definition and Units:	Ratio of total jobs to total employed residents assuming a constant 1.4 workers per household.
Illustrative Scores:	0.2 would represent a predominantly residential area; 1.0 would represent a perfect balance of jobs and workers; 2.0 would represent a predominantly non-residential area.

Indicator Name:	**Land-use diversity.**
Definition and Units:	0-1 index of sketch area population/employment mix compared to regional population/employment mix.
Illustrative Scores:	Scores near 1 represent sketch area mixes that are similar to regional mixes; lower scores reflect less similarity between sketch area and region.

Housing

Indicator Name:	**Residential density.**
Definition and Units:	Dwelling units per net acre of all land designated for all residential uses.
Illustrative Scores:	4 to 5 DU/acre for low-density areas; 50 to 60 DUs/acre for high-density areas.

Indicator Name:	**Single-family housing share.**
Definition and Units:	Single-family percent of total dwellings.
Illustrative Scores:	Varies widely depending on community and sketch area, e.g. 40-80%.

Indicator Name:	**Multi-family housing share.**
Definition and Units:	Multi-family percent of total dwellings.
Illustrative Scores:	Varies widely by community type and sketch area, e.g. 10-40%.

Indicator Name:	**Housing transit proximity.**
Definition and Units:	Percent of dwellings within 1/4 mi. of transit stops.
Illustrative Scores:	Varies widely based on extent of transit services, e.g. 10-30%.

Indicator Name:	**Housing recreation proximity.**
Definition and Units:	Percent of dwellings within 1/4 mi. of parks.
Illustrative Scores:	Varies based on extent of neighborhood park system, e.g. 10-30%.

Indicator Name:	**Residential energy use.**
Definition and Units:	Energy consumed for housing and auto travel in million Btu per year per capita.
Illustrative Scores:	75-200 MMBtu/year/capita. Scores will vary widely depending on combinations of climate and travel mode shares.

Indicator Name:	**Residential water use.**
Definition and Units:	Water consumed for interior and exterior residential purposes in gallons per capita per day.
Illustrative Scores:	100 to 150 gal/day/capita.

Employment

Indicator Name:	**Employment density.**
Definition and Units:	Number of employees per net acre of land designated for employment uses.
Illustrative Scores:	5 to 10 employees/acre for low-density employment areas; 50 to 60 employees/acre for high-density employment areas.

Indicator Name:	**Employment transit proximity.**
Definition and Units:	Percent of employees within 1/4 mi. of transit stops.
Illustrative Scores:	Varies widely based on extent of transit service, e.g. 10-30%.

Travel

Indicator Name:	**Sidewalk completeness.**
Definition and Units:	Percent of total street frontage with improved sidewalks on both sides.
Illustrative Scores:	10-90%.

Indicator Name:	**Pedestrian route directness.**
Definition and Units:	Ratio of shortest walkable route distance from outlying origin points to central node destination versus straight line distance between the same points.
Illustrative Scores:	1.20-1.50 is relatively favorable; scores above 1.5 are unfavorable.

Indicator Name:	**Pedestrian design index**
Definition and Units:	0-1 (1 is high) composite indexof sidewalk completeness, street network density, and pedestrian route directness indicator scores.
Illustrative Scores:	0.7 or higher is favorable.

Indicator Name:	**Street network density.**
Definition and Units:	Density of streets in centerline miles per sq.mi.
Illustrative Scores:	5-20 mi. per sq.mi.

Indicator Name:	**Street connectivity.**
Definition and Units:	Ratio of street intersections versus intersections and cul-de-sacs, expressed on a scale of 0 to 1 (1 is high).
Illustrative Scores:	0.6 or less is unfavorable; 0.8 or higher is very favorable.

Indicator Name:	**Vehicle miles traveled.**
Definition and Units:	Average total vehicle miles traveled daily per capita.
Illustrative Scores:	15 VMT/day/capita in dense multi-modal areas; 25 VMT/day/capita in low-density auto-dependent areas.

Indicator Name:	**Vehicle trips.**
Definition and Units:	Average total vehicle trips daily per capita.
Illustrative Scores:	4-5 VT/day/capita.

Indicator Name:	**Auto travel costs.**
Definition and Units:	Annual average household cost for auto travel in $/year based on American Automobile Association cost per mile data and VMT estimate.
Illustrative Scores:	$5,000 - 10,000 year.

Environment

Indicator Name:	**Open space.**
Definition and Units:	Percent of total sketch area in user-defined open space land-use classes.
Illustrative Scores:	Varies depending on general vicinity (urban, suburban, exurban), and user definition of open space.

Indicator Name:	**Park space availability.**
Definition and Units:	Acres of park and school yards per 1,000 residents.
Illustrative Scores:	2 to 3 acres per 1,000 residents.

Indicator Name:	**Carbon monoxide (CO) emissions.**
Definition and Units:	CO emitted from light vehicles in lbs/year/capita.
Illustrative Scores:	200-300 lbs/year/capita.

Indicator Name:	**Hydrocarbon (HC) emissions.**
Definition and Units:	HC emitted from light vehicles in lbs/yr/capita.
Illustrative Scores:	15-25 lbs/yr/capita.

Indicator Name:	**Oxides of Sulfur (SOX) emissions.**
Definition and Units:	SOX vehicle emissions in lbs/yr/capita.
Illustrative Scores:	10-15 lbs/yr/capita.

Indicator Name:	**Oxides of nitrogen (NOX) emissions.**
Definition and Units:	NOX emitted from light vehicles in lbs/year/capita.
Illustrative Scores:	15-25 lbs/year/capita.

Indicator Name:	**Particulate matter (PM) emissions.**
Definition and Units:	PM vehicle emissions in lbs/year/capita.
Illustrative Scores:	1-10 lbs/yr/capita.

Indicator Name:	**Carbon dioxide (CO_2)**
Definition and Units:	Carbon dioxide emitted from light vehicles in lbs/year/capita.
Illustrative Scores:	7,000-10,000 lbs/year/capita.